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Par Louis DUPUY

Soutenabilité et Commerce International
Sustainability and International Trade

Sous la direction de Jean-Marie Cardebat, Professeur des universités

Soutenue le 16/06/2014

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English speakers are therefore directed straight to page iii, les francophones peuvent quant à eux commencer au paragraphe suivant.

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“Unless we succumb to the forces of chaos and folly, the transition to a planetary civilization is inevitable, the end product of the enormous, inexorable forces of history and technology beyond anyone’s control.”

Dr. Michio Kaku, theoretical physicist.

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Classification-JEL – B13,F11,F17,F18,Q01,Q32,Q33,Q37,Q51,Q56,Q58

Introduction

L'émergence du paradigme de la soutenabilité à partir des années 1970 est un changement majeur pour l'analyse économique actuelle. La définition d'un développement durable implique de prendre en compte à la fois les *moyens* et des *fins* du développement humain. La soutenabilité est l'étude des *moyens* du développement, qui viennent ensuite servir des fins socialement définies. Les préoccupations liées à la soutenabilité font partie de la pensée économique depuis le 19^{ème} siècle, mais deviennent avec la montée des questions environnementales un élément clef de la théorie économique. L'étude de la soutenabilité demande la prise en compte de questions normatives, liées aux besoins des générations futures, notamment les questions de justice et d'équité d'accès aux droits et aux ressources de la société. L'analyse économique standard doit donc être étendue.

L'étude du commerce international part de l'observation que le monde n'est ni un ensemble d'îles sans liens entre elles, ni un espace parfaitement intégré et unifié. Ce fait a d'importantes conséquences sur la théorie de la soutenabilité, qui est habituellement définie en économie fermée. Le commerce international a connu de nombreuses mutations dans son histoire récente, devenant d'inter-industriel intra-industriel puis infra-firme. La gestion sociale des facteurs reste cependant de la responsabilité des États, une source potentielle de conflits entre optimalité domestique et globale. La gestion domestique peut ne pas être systématiquement optimale, notamment si les États ne parviennent pas à épargner et réinvestir une part suffisante de la rente issue des ressources naturelles (Hartwick 1977). Le problème est plus aigu encore dans un contexte d'économie ouverte : il n'existe alors plus d'institution étatique centrale pour superviser la gestion des ressources non-renouvelables.

Il semble alors nécessaire de recenser et d'explicitier les mécanismes qui relient les évolutions du commerce international à la soutenabilité. Cette thèse a pour but de recenser et d'explicitier les mécanismes par lesquels le commerce international peut influencer durablement la soutenabilité. Nous suggérerons des amendements autant théoriques qu'empiriques aux indicateurs et aux théories de la soutenabilité sur la base des mécanismes de commerce présentés.

Les composantes conceptuelles de la soutenabilité

La soutenabilité est issue de la combinaison d'une théorie de la valeur et d'une théorie des moyens, la théorie du capital. La théorie du capital est d'abord formulée par Fisher (1906), comme la synthèse de nombreuses contributions et courants de pensée durant la seconde moitié du 19^{ème} siècle. La théorie du capital formalise les interactions entre les humains et leur environnement. Chaque élément constitutif de l'environnement constitue un stock, qui est une part de la richesse. Chaque instrument de richesse constituant ce stock est formé, alimenté ou maintenu par un apport de matière ou d'énergie (*outgo*) et génère un flux de services (*income*) parfois qualifié de revenu ou de bénéfices. Ces instruments de richesse prennent valeur dans le cadre des mécanismes de marché, formalisé par une théorie, actuellement utilitariste, de la valeur. Cette valeur provient de la rencontre des préférences des agents, de leurs utilités et besoins individuels. Une allocation de valeur par le marché dans le cadre de la théorie utilitaire génère une distribution optimale des ressources, au sens de Pareto : la plus grande satisfaction possible du plus grand nombre, compte tenu des droits de propriétés constatés.

Les Économistes écologistes les premiers ont proposé une alternative à la théorie utilitariste, sur la base d'objections concernant les possibilités de substitution (parfaite, imparfaite, impossible) entre différents instruments de richesse. Certains, suivant les conclusions de Georgescu-Roegen (1971), proposent un procédé d'allocation des ressources alternatif, basé sur la dégradation thermodynamique de l'environnement. Nous suggérons que malgré l'opposition souvent postulé dans la littérature entre économie environnemental et économie écologique, les deux courants pourraient se retrouver dans une théorie du capital convenablement définie. L'industrie écologique est un premier exemple au crédit de cette assertion. Il est néanmoins certain qu'une théorie de la valeur alternative est requise pour refléter les préoccupations concernant l'équité, la justice (Rawls 1971) et le niveau de substituabilité réel entre plusieurs instruments.

La soutenabilité à l'ère de la mondialisation

Le commerce international est basé sur la notion d'avantage comparatif (Ricardo 1817). Un avantage comparatif conduit le pays considéré à se spécialiser dans le bien ou le facteur procurant un avantage à l'échange vis-à-vis d'un partenaire. L'avantage comparatif est considéré comme donné dans les théories traditionnelles du commerce international. Des contributions plus récentes ont intégré l'impact de la distribution dans le temps et dans

l'espace des sources d'avantage comparatif, soulignant les mécanismes de formation endogène de ces mêmes avantages. Ces travaux font ressortir la nécessité de développer une "diversification des spécialisations", de ne pas concentrer à l'excès ses avantages comparatifs dans un nombre trop restreint de secteurs, facteurs ou biens. Cette diversification est obtenue par une politique avisée de réinvestissement et de maintenance des instruments de richesse. Il s'agit ici de gérer la part de ressources non-renouvelables et renouvelables, du capital économique, social et environnemental. La politique de réinvestissement des revenus du capital et de maintenance est donc déterminante pour la formation des avantages comparatifs, alors que les avantages comparatifs créés des incitations fortes à la spécialisation qui peuvent contredire les impératifs de la soutenabilité.

Cette potentielle contradiction intemporelle est plus prégnante encore du fait des dernières évolutions du commerce international, qui prend de plus en plus la forme d'une "chaîne d'approvisionnement internationale". Chaque pays se retrouve ainsi dépositaire d'une part du processus de production d'un bien, au lieu d'accueillir l'ensemble du processus et de faire commerce de biens de consommation ou d'équipement achevés. Les pays riches en ressources naturelles sont ainsi incités à prendre part au commerce international principalement en tant que fournisseurs de ressources naturelles, ce qui peut contraindre ou limiter leur développement par le changement structurel.

L'étude du paradoxe de la spécialisation est également d'importance pour la théorie du commerce international dans la mesure où le commerce des ressources naturelles représente une part en augmentation du commerce mondial, alors que les pays riches en ressources naturelles représentent déjà une part importante de la population mondiale. Le commerce international crée majoritairement de l'interdépendance entre les pays et non des relations de dépendance pures. Une théorie de la soutenabilité en économie ouverte, qui serait juste et équitable, demande donc le rétablissement de la compatibilité entre la formation de spécialisations productives en lien avec le commerce international et le changement structurel requis pour un développement durable. Si cet équilibre ne peut être trouvé, le commerce international ne peut prétendre bénéficier à tous les acteurs de la chaîne d'approvisionnement mondiale.

1 Le développement soutenable en économie : l'émergence de la soutenabilité

Le paradigme de la soutenabilité faible, basé sur la vision néoclassique, est le principal paradigme de la théorie de la soutenabilité. Ce paradigme est basé sur la combinaison de la théorie du capital et de la théorie utilitariste de la valeur. Nous nous basons cette tradition et sa traduction dans l'Épargne Nette Ajustée (ENA) pour proposer un modèle global de soutenabilité, mettant en avant les cinq dimensions de la soutenabilité.

Le modèle de soutenabilité faible est issue des contributions de [Dasgupta and Heal \(1974\)](#), [Solow \(1974\)](#) et [Stiglitz \(1974\)](#) qui forment le modèle DHSS, la base jusqu'à ce jour des études en soutenabilité faible. Le modèle est rapidement complété par la règle de Hartwick ([Hartwick 1977](#), [Asheim et al. 2003](#)) qui prescrit le réinvestissement de la rente issue des ressources naturelles en capital produit, afin de maintenir le niveau de la richesse globale et assurer la soutenabilité. Reste à estimer cette rente et plus généralement l'évolution des différents instruments de richesse disponibles dans l'économie considérée.

Le premier indicateur de soutenabilité est l'Épargne Nette Ajustée (ENA) proposée par [Pearce and Atkinson \(1993\)](#) suivant le modèle de [Solow \(1974\)](#). L'ENA est d'abord un projet empirique, avant de trouver une justification théorique dans les travaux d'[Hamilton and Clemens \(1999\)](#). Des doutes persistent quant à la capacité de l'ENA de prédire la soutenabilité future ([Ferreira and Vincent 2005](#)). L'ENA est cependant l'indicateur d'équité intergénérationnelle le plus robuste actuellement disponible. L'ENA est l'héritière directe des deux principales traditions du paradigme de la soutenabilité faible, supplantant le produit net national vert ([Dasgupta 2009](#)). L'indicateur est calculé par la Banque Mondiale ([The World Bank 2011](#)), qui le propose dans une base séparée (Wealth Accounting Database) et comme Indicateur de Développement dans le Monde (IDM).

Les institutions ont un rôle instrumental pour la soutenabilité, notamment dans les pays riches en ressources naturelles ([Van Der Ploeg 2011](#)). Nous offrons une lecture du cadre d'analyse proposé par [Acemoglu and Robinson \(2012\)](#) pour analyser l'impact des institutions extractives et inclusives sur la soutenabilité. L'évolution des institutions se fait par incréments successifs, qui peuvent favoriser la concentration graduelle de la richesse dans une partie de la population. Ce phénomène rend l'accaparement de la rente par une élite plus probable et le réinvestissement optimal de cette rente moins probable. Cette tendance potentielle est rendue plus problématique par des droits de propriétés mal définis ([Ostrom 1990](#)), particulièrement pour les biens publics et les espaces communs.

Une grande variété d'évolutions institutionnelles sont possibles, auxquelles s'ajoutent les "croisements critiques", qui représentent de grandes distorsions dans l'évolution institutionnelle (généralement des révolutions). Les analyses basées sur la notion d'équilibre de long terme ne semble donc pas les plus adaptées pour l'analyse de la soutenabilité si des contrôles efficaces concernant les évolutions institutionnelles sont impossibles.

Nous nous intéressons ensuite aux conséquences potentielles de ces équilibres multiples et de l'incertitude pour la soutenabilité, suivant en cela le chemin tracé par Hicks (1946). Nous concluons à la validité des objections formulées par Georgescu-Roegen (1971) sur l'importance de la locomotion qui devraient être prises en compte dans les études de soutenabilité. Les analyses contrefactuelles (Hamilton et al. 2006), basées sur des indicateurs en valeur courante et en valeur présente autour de l'ENA et de la richesse globale semblent les plus adaptées pour capturer la multiplicité des scénarios envisageables.

Nous concluons cette présentation par la présentation de notre cadre intégré pour la soutenabilité. La soutenabilité repose sur cinq dimensions qui doivent être considérées de façon conjointe et équitable :

- Le maintien d'un niveau de consommation constant en valeur sur l'horizon considéré.
- Le maintien d'un niveau de richesse global en valeur sur l'horizon considéré.
- Le contrôle du niveau effectif de substituabilité réel
- Le maintien d'une équité intergénérationnelle
- Le maintien d'une équité intragénérationnelle.

Les institutions organisées sur le principe de la subsidiarité sont les plus adaptées pour (et potentiellement les seules capables de) fournir le cadre nécessaire à la réalisation de ces cinq dimensions.

2 Commerce International et soutenabilité : exploration des liens

Nous avons proposé un cadre d'analyse cohérent regroupant les différentes dimensions de la soutenabilité en économie fermée. Nous allons maintenant transcrire ce schéma dans un cadre d'économie ouverte. La littérature est d'ors et déjà riche de contributions présentant les liens entre la soutenabilité et le commerce international partant d'autres champs d'analyse. Nous tentons une synthèse sur la base des dimensions de notre cadre

de définition intégré.

Le corpus le plus important à ce jour est le corpus regroupant les contributions sur les liens entre commerce international et impacts environnementaux (pollution aérienne, des sols et de l'eau). Basé sur le modèle de [Copeland and Taylor \(1994\)](#), cette littérature décrit l'évolution d'un système économique face aux dommages environnementaux, selon les effets d'échelle, de technique et de composition. Le modèle apporte un important éclairage sur les débats concernant la courbe de Kuznets environnementale et l'hypothèse des havres de pollution.

Vient ensuite, en termes de contribution, la littérature analysant l'économie des ressources naturelles dans un cadre d'économie ouverte. Cette littérature regroupe les règles de soutenabilité en économie ouverte ([Asheim 1986](#)) et les études sur l'impact de la volatilité des prix mondiaux ([Hartwick 1995](#), [Vincent et al. 1997](#)) sur les sentiers d'exploitation des ressources naturelles. Cette littérature trouve un débouché empirique dans les études sur le contenu en ressources naturelles des flux commerciaux ([Proops et al. 1999](#)), qui donne aujourd'hui lieu à des calculs de "soutenabilité virtuelle" ([Atkinson et al. 2012](#)) à comparer aux taux d'ENA domestiques.

Notre proposition de synthèse commence par une revue des contributions, moins nombreuses, concernant le rôle des instruments de politique commerciale dans un contexte de soutenabilité ([Flaaten and Schulz 2010](#)). Nous présentons ensuite l'impact de l'ouverture économique sur les cinq dimensions de la soutenabilité. Les textes du corpus traitant de la soutenabilité en économie ouverte sont basés sur l'hypothèse implicite que le monde se dirige vers l'unification de l'espace en un marché commun : l'alternative serait l'enfermement dans le cadre national. Ce mouvement serait inexorable du fait des gains d'efficacité et de bien-être attendus.

La réalité, qui justifie les études du commerce international est un entre-deux imparfait. Pour faire face à cette situation, de nouveaux mécanismes institutionnels sont requis, pour éviter les phénomènes de polarisation des ressources dans certaines régions ou groupes de population de par le monde. Ces mécanismes incluent notamment des politiques de redistribution/réinvestissement : ils doivent contrer la tendance du commerce international à redistribuer la richesse à l'encontre des impératifs de soutenabilité. Cette nécessité est rendue plus pressante encore par la place prise par l'incertitude sur les temps futurs ou concernant le niveau réel de substituabilité entre les différents instruments de richesse. Face à ces limites indépassables des mécanismes de marché, l'usage d'instruments de politique commerciale nous semble justifié, dans le respect du principe de précaution.

3 Un modèle dynamique pour la soutenabilité en économie ouverte

Nous présentons un modèle global d'évaluation du changement structurel dans un contexte d'économie ouverte. Ce modèle nous permet d'explorer différents sentiers de développement, basés sur diverses règles de soutenabilité et de réinvestissement.

La littérature sur la soutenabilité s'est tournée vers les modèles dynamiques (Cheviakov and Hartwick 2009) pour étudier les dynamiques d'accumulation des différents instruments de richesse. Parmi les variables déterminantes pour cette classe de modèles, le niveau des taux d'escompte pour la formation des dynamiques doit être correctement évalué (Bogmans and Withagen 2010). Nous nous basons pour la réalisation de notre modèle sur différentes contributions de la littérature néoclassique sur la croissance, de la littérature sur la soutenabilité et de la littérature sur les modèles Heckscher-Ohlin de commerce international.

Nous partons du modèle proposé par Cuñat and Maffezzoli (2004) pour construire un modèle associant une composante dynamique (qui régie l'accumulation des instruments de richesse) et une composante statique (qui détermine les prix des facteurs). Nous proposons quatre instruments de richesse synthétiques (le travail, le capital produit, le capital épuisable renouvelable et le capital épuisable non-renouvelable). Nous évaluons les dynamiques d'accumulation sous l'hypothèse d'égalisation des prix de facteurs mondiaux, et lorsque cette hypothèse est violée : les prix de facteurs sont alors déterminés pays par pays.

Le modèle produit des sentiers d'expansion pour chaque instrument de richesse, selon une résolution séquentielle. On considère une distribution exogène des instruments de richesse à la première période. Les prix des facteurs et des biens sont d'abord déterminés dans la composante statique. Ils sont ensuite utilisés pour déterminer le niveau de chaque instrument de richesse à la période suivante et ainsi de suite. Lors de la résolution, un instrument de richesse est accumulé de façon endogène dans chaque pays, les autres suivent un profil d'accumulation contraint (exogène). Cette méthode nous permet d'évaluer la convergence potentielle des niveaux de consommation et de richesse lorsque l'asymétrie dans la distribution des instruments (qui est la base de la spécialisation internationale dans un modèle Heckscher-Ohlin) se réduit par les politiques de réinvestissements. Nous comparons notamment le cas où les deux pays représentatifs accumulent de façon endogène le même instrument au cas où ils accumulent deux instruments différents.

Il ressort de notre analyse que de multiples sentiers de développement sont possibles selon la règle de soutenabilité suivie. Notre scénario de base est construit en partant d'une réduction symétrique de l'asymétrie de la distribution des instruments de richesse exogènes dans les deux pays. Nous étudions également des situations de variation asymétrique de cette distribution, que ce soit dans le sens d'une accumulation ou d'une décumulation plus rapide d'un facteur exogène dans un des deux pays.

Nous concluons tout d'abord qu'une forte asymétrie de la distribution des instruments de richesse est préjudiciable aux deux pays, que ce soit en autarcie ou en libre-échange. Ce constat repose sur la technologie de production, qui suppose que l'ensemble des intrants sont requis dans le processus de production global. Dans ce cadre, s'ouvrir au libre-échange réduit le niveau de consommation dans les deux pays lorsque l'asymétrie de la distribution de la richesse est élevée.

Ce résultat découle de la nécessité de se spécialiser dans la production de certains biens intermédiaires pour former un avantage comparatif. Les pays produisent donc un segment de la gamme de biens intermédiaires et importent les autres. La baisse de la consommation globale vient des coûts engendrés par la complexification de la structure de production. Nous comparons ensuite les équilibres de long terme entre forte et faible asymétrie dans la distribution des instruments de richesse et concluons que les deux pays perdent moins à s'ouvrir à l'échange lorsqu'ils accumulent le même facteur de production.

Nous présentons la possibilité que des pays riches en ressources naturelles qui se concentrent sur la sauvegarde de leur capital naturel puissent passer par un changement structurel et se trouver relativement et absolument mieux en autarcie qu'en libre échange. Ce résultat suggère que dans un cadre dynamique, les pays qui se spécialisent dans les instruments accumulés au cours du changement structurel ont un avantage par rapport à ceux qui dépendent d'un instrument dont le stock doit être réduit dans le cadre du changement structurel. Dans ce cadre dynamique, les conséquences en termes de soutenabilité de spécialisations différentes ne sont pas les mêmes. Nous constatons également une réduction du volume des échanges avec la réduction de l'asymétrie de la distribution des dotations factorielles, un résultat conforme aux prédictions standards des modèles Heckscher-Ohlin.

Le fait que les pays se retrouvent face à des niveaux de consommation et de richesse plus faibles en libre-échange ne signifie pas que les sentiers d'expansions en libre-échange sont en tout point inférieurs. Les prix de facteur évoluent pour refléter la rareté globale (et non plus seulement domestique) ce qui produit des gains à l'échange pour les

producteurs. Ces changements dans le système de prix conduisent à un usage plus intensif de certains facteurs par rapport à la situation d'autarcie. Ce constat nous mène à demander le réinvestissement de ces gains dans le financement du changement structurel, suivant la logique de réinvestissement des rentes et la règle de Hartwick. Ceci ne signifie cependant pas que l'ensemble des gains de l'échange doivent être épargnés puis réinvestis. Les gains venant d'un progrès technique Hicks-neutre (qui améliore la productivité toutes choses égales par ailleurs) ne sont pas concernés.

4 Soutenabilité, institutions et interdépendance dans les processus de développement

Nous avons conclu le chapitre précédent en soulignant la nécessité d'épargner et de réinvestir certains des gains à l'échange international. Le volume des échanges provenant de l'asymétrie dans la distribution des facteurs diminue à mesure que cette même asymétrie se réduit. Cette diminution du commerce inter-industriel basé sur les facteurs s'est en fait accompagnée empiriquement de l'émergence d'un commerce intra-industrie, entre pays ayant une distribution des facteurs similaire. Nous explorons les conséquences de ce fait du point de vue de la soutenabilité.

Le modèle d'[Ethier \(1982\)](#) nous permet d'évaluer l'incidence des rendements d'échelle croissants sur les conclusions présentées au chapitre précédent. Nous concluons que même si les rendements croissants ne changent pas l'allocation des facteurs dans une perspective statique, ils ont un effet important sur les sentiers des prix de facteur en dynamique. Considérée période par période, l'allocation des facteurs ne change pas avec les rendements d'échelle, mais les variations de prix entre les périodes créent en dynamique un résultat différent.

En conséquence, les gains à l'échange issus des rendements d'échelle croissants doivent eux aussi être épargnés et réinvestis. Il est également possible qu'un pays progresse plus rapidement que ses partenaires dans la voie du changement structurel. Les partenaires seraient alors potentiellement maintenus dans une spécialisation condamnée à l'obsolescence à long terme. Les partenaires commerciaux ont alors moins de ressources pour entreprendre le changement structurel sur le long terme, à rebours de leurs intérêts de court terme de surcroît.

Nous présentons ensuite brièvement la littérature sur la malédiction des ressources

et le syndrome hollandais (avec notamment l'importante contribution de [Van Der Ploeg \(2011\)](#)), dans la mesure où cette littérature illustre parfaitement l'interaction du commerce international et des institutions. L'explication privilégiée par la littérature pour la malédiction des ressources est institutionnelle. Nous défendons la thèse que les facteurs institutionnels et les incitations du commerce international jouent de concert et sont impossibles à distinguer sur le plan logique. La malédiction des ressources ne peut ainsi se comprendre que du fait de l'interdépendance internationale générée par le commerce.

Pour appuyer cette thèse, nous proposons un test économétrique basé sur le commerce "intra-industriel" des biens intensifs en ressources naturelles. Nous montrons que le commerce inter-industriel domine pour ces biens dans les pays riches en ressources naturelles. Ce résultat nous emmène à conclure que les pays riches en ressources naturelles réduisent l'asymétrie de leur distribution d'instrument de richesse par une diminution absolue du stock de capital naturel et non par une diminution relative liée à la hausse des autres stocks. Nous suggérons donc d'utiliser la structure des échanges internationaux, notamment la différence entre commerce inter et intra-industrie dans les biens intensifs en ressources naturelles, comme un indicateur d'insoutenabilité du développement.

Nous proposons finalement d'utiliser une expérience naturelle pour distinguer l'importance respective de l'abondance en ressources naturelles et des évolutions institutionnelles pour expliquer la trajectoire en terme de soutenabilité d'un pays donné. Selon nous, la chute de l'Union Soviétique crée une rupture critique commune à l'ensemble des anciennes républiques socialistes, ce qui permet une analyse des évolutions à partir d'une base commune dix ans après¹.

Les différences de taille des stocks de capital naturel entre les ex-républiques sont également observables. Nous choisissons comme cadre d'analyse la Fédération de Russie et montrons comment sa performance en terme de soutenabilité (estimée grâce à l'ENA) se rapproche de pays proches sur le plan institutionnel mais pauvres en ressources naturelles et non de pays riches en ressources naturelles mais sans liens institutionnels. Nous présentons finalement des scénarios d'investissement contrefactuels pour la Fédération de Russie en suivant la méthode utilisée par [Hamilton et al. \(2006\)](#) et la Banque Mondiale ([The World Bank 2011](#)). Nous concluons que la comparaison des trajectoires d'investissement contrefactuelles devrait faire partie intégrante de toute étude de soutenabilité, afin d'appréhender pleinement les conséquences cumulative des décrochages par rapport aux stratégies de réinvestissement optimal. Nos résultats suggèrent que la malédiction des res-

1. Ce délai est retenu pour des raisons de disponibilité des données et pour éviter les chocs de court terme liés à la dislocation de l'Union Soviétique

sources devrait être traitée à l'échelle régionale, pour tenir compte des interactions entre le pays victime et les partenaires commerciaux ayant une proximité institutionnelle.

Conclusion

Nous avons proposé au cours de l'exposition de notre thèse une exploration des nombreux liens entre le commerce international et la soutenabilité. D'un point de vue théorique, la soutenabilité est basée sur l'application de la théorie utilitariste de la valeur à la théorie du capital. La théorie du capital permet de conceptualiser la relation entre l'homme et son environnement. Nous montrons comment la soutenabilité est en fait la gestion sensée et équitable des moyens du développement. Il s'agit plus précisément de maintenir un niveau de consommation et de richesse en valeur, d'encourager et de renforcer l'équité intragénérationnelle et intergénérationnelle et de contrôler le niveau de substituabilité physique entre les instruments de richesse.

Nous choisissons l'Épargne Nette Ajustée (ENA) comme indicateur de soutenabilité de référence pour évaluer la façon dont des économies ouvertes au commerce international voient leurs sentiers de développement être modifiés. Nous montrons que l'ouverture commerciale devrait donner lieu à plus d'épargne et d'investissements et que les gains à l'échange provenant de modifications du système de prix relatif domestique ne devraient pas être consommés. Nous présentons finalement des impacts plus larges des flux commerciaux sur les sentiers de développement, soulignant l'importance de prendre en compte les rendements d'échelle. Nous étudions également l'imbrication des effets du commerce international et des évolutions institutionnelles à la racine de la malédiction des ressources et d'une gestion sous optimale des ressources naturelles dans les pays où elles sont abondantes.

Pour mieux comprendre l'importance des institutions, nous proposons d'utiliser la dislocation de l'Union Soviétique comme expérience naturelle. Nous montrons que l'évolution de l'ENA en Fédération de Russie suit de plus près celle de ses voisins institutionnellement proches (et ce quelque soit leur dotation en ressources naturelles) que celle des pays de part le monde ayant un niveau de dotation en ressources naturelles similaire. Nous présentons enfin une étude contrefactuelle des sentiers de développement en Russie, proposant d'utiliser cette méthode de façon systématique pour évaluer la soutenabilité des pays dans un contexte d'incertitude et d'imprécision des données nationales concernant la richesse globale et la dépréciation réelle des actifs, naturels ou autre.

Ces différents éléments sont à considérer au mieux comme les premières pierre d'un modèle de soutenabilité élargi. Nous rejoignons [Arrow et al. \(2010\)](#) concernant le besoin de proposer une théorie pour relier les évolutions institutionnelles et les modèles de soutenabilité existants. Un tel modèle permettrait de calculer précisément la contribution du commerce international à la soutenabilité, permettant une identification des flux commerciaux allant à l'encontre de la préservation de la richesse globale. Utilisée avec des indicateurs en valeur présente pour évaluer les *fins* du développement, l'ENA pourrait alors légitimement être considérée comme l'indicateur représentant l'évolution de la soutenabilité des *moyens* du développement.

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General Introduction

IT is now widely acknowledged that the last 40 years of human history saw a dramatic change in the relationship between mankind and the planet. Some have considered this change to be a new geological age, called the anthropocene¹. The anthropocene is characterised by the emerging capability of mankind to modify the environment and the living conditions on earth, as opposed to previous eras where environmental shocks such as ice ages were imposed on mankind, who adapted usually by migrating.

The answer to this new state of the planet took the form of a push for sustainable development, as a way to mitigate the consequences of potentially harmful human action on vital components for the survival of all in the environment. The landmark definition for sustainable development was proposed by the United Nations World Commission on Environment and Development (WCED) which produced in December 1987 a resonating report, *Our Common Future*. The publication, sometimes referred to as the *Brundtland report* after the chair of the commission, defined sustainable development as “The development that meets the needs of the current generation without compromising the ability of future generations to satisfy theirs” ([World Commission on Environment and Development 1987](#)).

Sustainable development was to be a new coordinated effort to achieve a development that would be equitable and lasting for both developed and developing countries. Thirteen years later, the Millennium Summit propelled the Millennium Development Goals (MDG) as an expression of this imperative. The MDG are quantifiable targets for countries, the expression of sustainable development in observable dimensions. The [World Commission on Environment and Development \(1987\)](#) definition is very broad and consensual, but by no means operational. The key concept is obviously development, already ambiguous before even considering whether it is sustainable or not. As a full-scale report would be necessary to review the definitions of development, we will focus in this introduction on the most common conceptions.

To economists, development is the process by which emerging economies catch-up with advanced economies. Development is a multi dimensional concept, encompassing several aspects of life. Development is to be understood as the nexus maximising the individual’s possibilities of development inside a social fabric, situation, context that itself is made efficient in terms of resources and guaranteeing a harmonious cohabitation of the individuals. Development is

1. The anthropocene then starts at the end of the eighteenth century, with the industrial revolution in the United Kingdom. It is worth noting that the term anthropocene is gaining momentum in the scientific community, but is not yet recognised as a proper geological age.

therefore to be understood as the ultimate goal of the human species. As a species, humans are by definition biologically homogeneous, but they exist in an impressive diversity of social organisations and individual behaviours.

This implies that development can differ in nature and objectives across geographic situations and social groups. Different social structures can promote different forms of development, depending on the interactions between individuals and society, or groups within the wider society. To use a Marxist analytical tool, the superstructures of different social groups can differ and the resulting perceptions of development and development processes themselves are likely to differ. Common goals do not (and probably should not) guarantee an uniformity of social forms and implementation procedures.

Two broad categories of development have been highlighted in the course of western history (Rampnoux 2010). The first tradition dates back to ancient Greece. Greek philosophers believed the world was slowly decaying from its peak: the best possible option was to temporarily stall decline. Ancient Romans on the other hand believed in expansion and progress. Those two opposite traditions still coexist today, although the dialogue is biased by the *de facto* victory of the idea of progress after the rise of Humanism and the Enlightenment.

Today, societies envision development as either an eternal expansion based on technical progress, economic growth and growing population or a form of symbiosis with the environment which precludes extensive growth. In this second scenario, human beings reach rapidly a state of symbiosis with the environment and an ever reproducing steady state society unfolds².

In both cases, but more acutely in the first one, the question of the sustainability of development arises quickly. Sustainability here is in very general terms, an unaltered and controlled evolution of the dimensions by which development is assessed. If development is understood in the Greek sense, then sustainability is merely preventing degradation (homoeostasis). In the Roman sense, sustainability becomes creating the conditions for the driving forces of progress and expansion to sustain that expansion.

Development can therefore be translated as the question of sustaining the *means* to an *end*, leaving us with the need to define the reality behind those terms. This has been the mainstream understanding amongst economists at the very least. The ends of development are described using a theory of social and individual needs and wants. The means are described by a theory of the relationship between human capabilities and the material and immaterial environment. Putting it another way, the question of the ends is the question of why would humans interact

2. This distinction does not take into account societies striving for the return of an old order from the past, an idealised level of past development. The Greeks already knew that reaction was unworkable.

with their environment. The question of the means is the question of how to apprehend those interactions.

It seems intuitive that a growing amount of means will allow for bigger ends or make current ends easier to achieve. But a simple reference to the classical laws of matter (Georgescu-Roegen 1971) makes the point that extensive growth of means cannot last for ever. In a similar vein, the possibility of the needs and wants of society growing beyond its ability to satisfy them has been debated since at least Malthus (1817). As explained by Wrigley (2010), classical economists, especially David Ricardo, had total faith in the law of diminishing returns and predicted any growth in means would ultimately stall, as the environment could not handle infinite growth. Wrigley (2010) shows that an extensive growth process existed in Europe from the 1500's onwards. This process was however barely perceivable as it was limited by the energy available to "fuel" the transformation of matter, i.e. the production processes developing in those emerging economies. Hence, energy is often described as the most basic mean of social groups.

At this stage a first interesting parallel can be drawn. Development as advertised in the MDG is the Roman form of development and the object of development economics. Sustainable development is the recognition of the physical fact that development, although *de facto* happening in a diversity of ways, face limits in terms of means. Therefore, if ends are to be reached, some rules concerning the means are to be set to reflect on the realities of the social and physical environment. Similarly, the study of the means originally targeted the condition of the "Roman", i.e. continuous, expansion of the means. This is the study of economic growth.

As studies of economic growth gained momentum (Solow 1956), a very "Greek" realisation that there could be limits to economic growth gained traction. The seminal work here is obviously the first Meadows et al. (1972) report on *The Limits to Growth*. Although the predictions of the report were proven wrong (see chapter 1, section I.2), the general message is still valid. This first report led to the emergence of sustainability as an object of scientific investigation. Sustainable Development is the characterisation of the Roman progress of mankind in all its dimensions once all the potential constraints to expansion have been taken into account. Similarly, sustainability is the study of the means, expansion, depletion and allocation, that are instrumental to sustainable development. Following this distinction and definition of terms, this thesis is not concerned with sustainable development, but with sustainability.

We stressed the possibility of different groups having different conceptions of development, creating different superstructures as a result. Even if common ground is found about the best way to describe global needs and wants as in the MDG, the conceptual goals are still a matter of debate. The picking of these goals and the resulting social management is presented in

chapter 1, section II.1. Social scientists describe the sets of rules, conventions and habits as institutions, less associated with the Marxist theory than superstructure. We will from now on use that term to describe those elements independently of the theories describing the needs, wants and means. Note that institutions (as many dimensions of development in this thesis), have both an instrumental value and an intrinsic value. The intrinsic value comes from the ends, the social goals the institutions fulfil (tribunals exist to materialise the ideal of justice) and the instrumental value comes from the contribution to allocation and conflict resolution issues (tribunals are a legal conflict resolution mechanism critical to the existence of property rights).

Sustainable development in its common meaning has an ambiguous status. The definition in the Brundtland report stresses the complexity of defining development by not defining it. It adds the constraint of sustainability to what can either be understood as a process, a path, the co-evolution of a set of variables, indicators and phenomena or a state, a social condition. Finding a way out of this ambiguity is beyond the scope of this thesis, but it is worth removing it from the start. We consider, quite similarly to Dasgupta (2001), that development is associated with the global process or path characterising the evolution of a society. This path is characterised and determined by elements and decisions reaching beyond the object of economics.

We consider the economics of sustainable development to study a subset of variables and dimensions related to the means put in motion to achieve the broader social goals of development, as set by individuals and society as a whole. It is to mark this distinction that we will use the expression sustainable development when referring to those broader goals and aspirations and sustainability when referring to a sustainable management of the means. Beyond the fundamental goal of clarity of expression, the distinction matters for two reasons.

First, it provides a first way to define the object of sustainability economics and a refutation of the idea that all decisions are in essence economic decisions. Economic analysis should, in our view, always be ambitious in scale but modest in scope. Economic issues are always delimited by social choices, materialised by law, customs and culture. Second, the distinction is useful to have when considering variables of interest in empirical studies. It helps to differentiate between variables related to the instruments, the means, and those related to the goals, the finality set by society for development. All in all, sustainability appears as a subtopic of sustainable development.

It is no accident that the first book which endeavoured to propose both a theory of social and individual needs and wants and a theory of the relationship between human capabilities and the

material and immaterial environment is considered the first and founding step of economics³. Adam Smith's *Inquiry into the Nature and Causes of the Wealth of Nations* in 1776 proposed operational definitions for the concepts of value and wealth, describing how a given social organisation (around the “invisible hand”) provided the prerequisites for the development of nations.

Smith (1776) defined wealth as “the annual produce of the land and labour of the society” and proposed a theory of value to define this produce based on labour. This was the first step of a debate, still not closed, about the true nature of wealth and value. From Adam Smith onwards, economics as a social science has always been an endeavour to combine a social theory of value with instruments to allocate resources in line with this theory. We review in chapter 1 the combination of capital theory and the neoclassical theory of value as the basis for weak sustainability analysis.

I The building blocks of sustainability

Economic theory coined several concepts to build a theory of means and ends. As those concepts are still at the very core of sustainability, it seems useful to understand their origin and the phenomena they refer to. In the first part of this section we present the key concepts of wealth and income as integrated into capital theory, based on the early works of Fisher (1906). We then review utilitarianism, the theory of value at the core of neoclassical economics. We conclude by presenting the ecological economics critique, which provided sustainability with a *raison d'être* by emphasizing the potentially limited substitutability between different instruments of wealth.

I.1 Wealth, capital theory and income

First, chronologically and logically comes the theory of the means in economics. We use the umbrella term “capital theory” although legitimate objections could be made against this use. A first objection is that some of the cited authors did not think of their contribution in terms of capital theory. A second objection is that the term *capital* is associated with an economic system, capitalism, that is usually defined as an economic organisation, more encompassing than a “simple” theory of means⁴. A third objection is that capital theory as it is understood

3. As suggested by Dasgupta (2001, p.30).

4. In a presentation on the 4th of June 2013 on the future of capitalism at the London School of Economics, Pr. John Kay suggested that the term capitalism had lost any use as a concept, as the reality of the 21st century

today is concerned with more and less of “capital” at the same time, than we are considering here (see for example [Bliss et al. \(2005\)](#)).

To objection number two, which seems to us to be the most legitimate, we answer that sustainability is precisely about providing a framework that can interact with different economic systems (different in terms of institutions and/or superstructure). To all three objections, we answer that it is only by limiting the use of the word capital (or by using another word for it) to the quintessential properties of it, that much confusion can be avoided and the concept be put to good use. The aim of this section is precisely to show how a single conception of capital and wealth appears to be a sound foundation for sustainability.

As hinted in the previous paragraph, capital theory is plagued with endless controversies. The definition of wealth proposed above by [Smith \(1776\)](#) “the annual produce of the land and labour of the society”, suggest that wealth and capital are both related to production and the ability to generate value. Prior to Smith, the Physiocrats thought differently. [Richard Cantillon \(1755\)](#) and [Francois Quesnay \(1758\)](#) defended the idea that land was the only source of value and the ultimate constraint on economic and societal activity. Only the surplus generated from land could allow the “unproductive classes” to prosper and provide manufactures.

In essence, the Physiocrats were defending the idea that value can only emerge from land as manufacturing is merely about passing value extracted from land to the consumers. Capital, associated with the manufactures, was therefore non productive. The debate continues after Smith⁵. Briefly into the twentieth century, an important contribution is brought by [Fisher \(1906\)](#) in *The Nature of Capital and Income*. His goal is to define value, income and wealth in a theory that is internally consistent.

His concepts have been the implicit or explicit (depending on the author) foundation of the neoclassical theory of value, exposed below. Fisher starts by emphasising the link between wealth and property rights. Ownership is the cornerstone of any capital theory because ownership creates the right to use according to one’s will. “A property right is the right to the chance of obtaining some or all of the future services of one or more articles of wealth”(Fisher 1906, p.22).

According to Fisher, wealth needs only fulfilling two conditions: it must be material and it must be owned. Wealth is instrumental in providing services to the human mind, and this is the only reason for wealth accumulation. The objects composing wealth are called instruments of wealth. Instruments of wealth yield services which are “the desirable changes effected (or

was the dissociation of ownership and control of the means of production.

5. A presentation of this debate in the nineteenth century can be found in [Fisher \(1906, p. 53-57\)](#).

the undesirable changes prevented) by means of that instrument” (Fisher 1906, p.19). Wealth being defined extensively as Fisher did, property rights are the rights to the uses of wealth for its services. The desirability of those services are entirely subjective and depend on the user, but the desirable service is objective and in principle observable and measurable. Each of those instruments are items of capital. There can be several forms of capital or instruments of wealth: Fisher distinguishes between land, commodities and human-beings (Figure 1). It is worth stressing that, as made clear by the classification, what would be considered consumption goods in modern terms are part of wealth for Fisher as they are material and can be owned. They are an instrument of wealth and therefore they are capital. The time during which an instrument can provide services to the human mind makes no difference of nature: all goods are to be classified as capital. As for services, they are considered to be income provided by another instrument of wealth, which is the human body. What contemporary writers identify as a service is therefore not different from the services provided by capital.

Instead of calling services only services provided by the capital item which is the human body, services are the services provided by any form of capital. Satiety provided by an apple to the human body is a service provided by an item of capital to another. It should by now be clear that wealth and capital are synonymous in Fisher’s analysis. The materiality between both concepts is indeed not different in nature, but Fisher tends to save the use of the term capital as an adjective for some instruments of wealth. For example, the instrument of wealth named money is money capital.

“Wealth is wealth only because of its services. And services are services only because of their desirability in the mind of man, and of the satisfactions which man expects them to render”(Fisher 1906, p.41). Capital is a fund, or stock of wealth at any given period of time. It yields a service of wealth, which is a flow. When capital yields a flow of services, the flow is called “income”. When capital is abounded by disservices rendered to it, the flow is called “outgo”. An essential property of capital in Fisher’s theory is its fungibility. The same fund of capital can take any physical form (or immaterial in the case of money) as income and outgo from one flow to the other seamlessly.

It is equivalent to hold capital in the form of two houses and turn it by income flows from those two house into money, then triggering income from money into shares from a listed company. Capital exhibits perfect substitutability between funds of capital. We cannot stress enough that any use of Fisher’s theory without explicit alteration of the concept of capital has therefore build-in the assumption of perfect substitutability.

Property (direct or via titles such as shares) to wealth gives right to part of the services generated by this wealth. As those services may not be of direct use to the owner (i.e. he

may not have desirability for those) some forms of capital were invented so as to make different services fungible in an integrated system of exchanges. Prominent amongst those means is obviously money, which in modern terms solves the problem of the double coincidence of wants. In this narrow definition, money is an intermediate instrument in exchanges which has the particularity of being accepted against other services in any transactions in a given area.

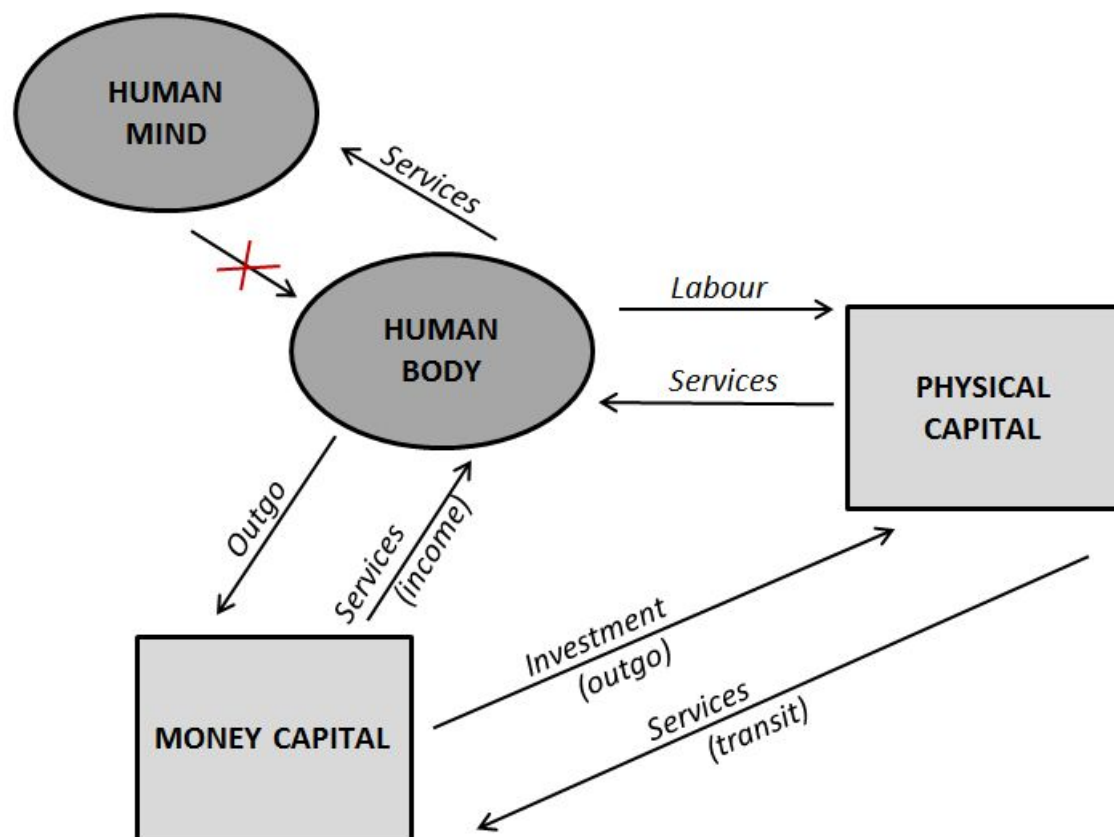
For example when a fund of money is debited as the agent adds a monetary flow to it, it is called outgo or disservices as those are services provided by the agent to his fund of money. When the agent uses this capital and money is credited, it is a service provided by this capital in money form to him. As it comes to him it raises his income at that time (flow of service from his money-capital to him) and with that extra income he can in turn get outgo from another form of capital (in an exchange of flows) which may provide a direct service. “if the outgo is in monetary form it is called expense; if it is in the form of human exertion it is called labor. It includes all of what economists have called cost, i.e. labor, trouble, expense, and sacrifices of all kinds” (Fisher 1906, p.119-120).

Wealth can be measured in physical units, weights units or space units, depending on what is most accurate. Those units must not be confused with qualitative dimensions which are not used to characterise an instrument, but to characterise the difference between two instruments. Fertile and non fertile lands are two different instruments and not one instrument with different characteristics. If one objects to this on the basis that some services have a single provider (Fisher uses the example of a Sarah Bernhardt performance), the logical conclusion is that this service is obviously unique as it can be provided by only one instrument. Instruments of wealth can then be measured in monetary units.

Fisher introduces a link to relate monetary value to transfers. “An article of wealth is said to be transferred when it changes owners”. So the notion of transfer is linked to the notion of ownership. Reciprocal transfers, which are the majority of transfers, are called exchanges. The price of the exchange is obtained by dividing the two physical quantities of wealth involved in the exchange to obtain a relative price. The price is in physical units or monetary units depending on the units used to measure the quantities of wealth. The product of quantities and price involved in the exchange is called the value of the amount exchanged.

Fisher does without a mechanism to set the quantities and therefore the prices involved in the exchange. He only considers that when entering a transaction, the seller has one price in mind (the ask price) and the buyer has a price at which he would like to buy (the bid price). The price at which the transaction takes place should be the half-way price. It is observable in recorded transactions. When such a price does not exist the observer should ask potential exchangers about their bid and ask prices (which is in fact willingness to pay (WTP)

Figure 2: Income and Outgo in Fisher's theory of capital



Source: Author from *Fisher (1906)*

and willingness to accept compensation (WTAC) and therefore contingent valuation) or try to make an appraisal by any means available. This is a first suggestion that when prices are not available and an estimate of wealth is needed, contingent valuation based on estimates of the WTP and the WTAC is legitimate.⁶

Fisher builds on this basis his theory of the rate of interest which he calls a value return, as it is the ratio of two quantities expressed in monetary terms (Fisher 1906, p.184). It is worth noting that the question of the value of income between the occurrence of income flows is treated at length by Fisher in the chapter 14 about interest. Fisher makes a difference between income and earnings to explain why and how capital value fluctuates when income flows are anticipated, which is the common case when capital is yielding annuity payments. The Fisher theory of capital and income is an internally consistent theory to link wealth and income. The main elements are summarised in figure 2.

6. Elaboration on WTP and WTAC can be found in Hanley et al. (2001) and in chapter 1 section I.2.

As noted above there is no mechanism to determine prices in Fisher's theory. Value is just price times quantities, but quantities are assumed to be available to the individual to start with, as in an Edgeworth Box. Growth in the modern sense happens in the economy only as capital is able to yield higher anticipated income flows, without the reason for this being explicitly specified by Fisher.

After Fisher, the next author to propose a critical contribution to the concept of capital is John R. Hicks. In *Value and Capital*, Hicks (1946) makes a critical assessment of the concept of income. Discussing income, savings and depreciation he justifies his decision to abstain from using those in his attempt to characterise economics by stating he does "not believe that they are suitable tools for any analysis which aim at logical precision" Hicks (1946, p.171). He justifies his aversion, stressing income can indeed be clearly defined in static analysis or at the steady state. Income is then equal to one person's receipts. "If a person expects no change in economic conditions, and expects to receive a constant flow of receipts, the same amount as he receives this week, it is reasonable to say that that amount is his income" (Hicks 1946, p.172).

Uncertainty or irregularity in the payment of receipts creates the need to differentiate between what is income and what is to be dedicated to maintaining capital constant. Why the focus on maintaining capital constant? According to Hicks, the purpose of income calculation is to "give people an indication of the amount which they can consume without impoverishing themselves" (Hicks 1946, p.172). Income defined as such is the upper-bound of "legitimate" spending. He also argues that if one is paid every month, this doesn't mean that the income of the three weeks before the week of payment is zero⁷. In *Value and Capital* income is meant to be an operational concept, an indicator of what would be in the common sense a sustainable way of life. A person consuming more than its income can expect to be worse-off in the week after the current week, and the other way around for a person consuming less than income.

But what would be the definition of income if it is to serve this practical purpose? Hicks offers three approximations, called income number 1, 2 and 3:

1. Income 1 is the "capitalized money value of the individual's prospective receipts" Hicks (1946, p.172). In contemporary terms, income can be calculated as the net present value derived from net interests on capital i.e. once investment to keep capital constant is subtracted from income. Income is then "the maximum amount which can be spent during a period if there is an expectation of maintaining intact the capital value of prospective receipts" (Hicks 1946, p.173).

7. Although Fisher's difference between realized income and earned income dispenses with this problem (Fisher 1906, p.255)

2. Income 2 is the “maximum amount the individual can spend this week, and still expect to be able to spend the same amount in each ensuing week”(Hicks 1946, p.174). This definition differs from the first only if the rate of interest is not constant.
3. Income 3 is the “maximum amount the individual can spend this week, and still expect to be able to spend the same amount in real terms in each ensuing week” (Hicks 1946, p.174). Definition 3 matters only if prices are expected to change.

Hicks concludes that using income is a general problem because “Strictly speaking, savings is not the difference between income and expenditure, it is the difference between income and consumption” (Hicks 1946, p.174). If one defines income as the maximum amount one can consume without impoverishing oneself, then there is a difference between what one can consume and what one can spend. That difference is the amount required to maintain capital constant, hence making sure the same amount of income will be available the next period. Expenditure therefore exceeds consumption in most periods and reciprocally savings are in fact divided between pure savings and investment to maintain produced capital.

Hicks considers that when receiving income, the agent must immediately spend (as investment) a share of it to compensate for the depreciation of capital, but this first expense should not be counted as income if income is to be the maximum amount one can spend without impoverishing oneself. A difference should therefore be introduced between for example gross income and net income, the difference between the two being investment to maintain capital constant. Only net income is the income satisfying the non-impoverishment condition. Instead, Hicks concludes from this apparent confusion that “we shall be well advised to eschew *income* and *saving* in economic dynamics. They are bad tools, which break in our hands” (Hicks 1946, p.177). It is somewhat puzzling to see Hicks fail to propose at least a simple trick (such as the gross/net income difference) to solve the problems he raises. A potential explanation for this is offered below.

How to articulate consumption investment and savings? A first solution is to consider income to be, as in Fisher (1906) the sum of services from capital at time t . Then it is possible to call “replacement investment” the first investment necessary to maintain capital (excluding money) constant. “Investment” becomes the outgo to capital (still excluding money) in excess of this “replacement investment”. “Savings” is then the outgo to money-capital and consumption, the residual from all those subtractions. In this solution, income does not satisfy Hicks’ definition and a difference Fisher would consider artificial is introduced between money-capital and non money-capital.

This solution also assumes that although receiving the entirety of its potential income and

being free to allocate it as he pleases, the agent always takes the decision to maintain capital constant before arbitrating between investment, consumption and saving. Against this solution it can therefore be argued that it assumes a form of “sustainability” to start with.

A second solution would be to follow Hicks’ definition of income to the letter and consider that the services that should be mobilised to maintain the beginning of the period level of capital are excluded of income as those cannot be consumed without impoverishing oneself. One has to picture either an accounting trick such as amortisation or an actual automatic “before-income” outgo to such a fund, physical or monetary. Only after this compulsory subtraction can the agent choose between savings and consumption.

The difference between solution 1 and solution 2 lies principally in the definition of income. It could therefore be argued that by accepting the gross/net income solution the problem is solved and the agent simply focuses on net income. But this answer only solves the beginning of period problem of what is income, it does not solve the problem of the articulation of investment and savings. We argue this difference is the reason why Hicks found the concept of income and saving to bring more trouble than light to the debate. In solution 1, we solved the problem of what is investment and what are savings by bringing an artificial difference between money-capital and physical capital.

This difference may have been accepted by the reader used to consider money as a peculiar form of wealth and automatically thinking that savings have a link to the future and therefore are essentially different. This interpretation does not add up in Fisher’s view of money as another form of perfectly fungible capital. If it is, then it should be equivalent to own capital as physical capital or money capital and there is no point in making a difference between investment in money and investment in physical capital.

The solution to this puzzle lies in the difference between beginning of the period capital and end of the period capital, regardless of the instrument involved and of the importance of uncertainty. In Fisher, the presentation of capital theory is made assuming that future flows of income generated by an instrument of wealth are known with certainty. Fisher does not recognise the difference between risk and uncertainty and assumes the future is only about risk. Hicks on the contrary sees the problems with neoclassical habits of thinking as his intention is to create a synthesis between the Keynesian view and the neoclassical mainstream. If there is uncertainty, then a form of wealth that could provide a hedge against it will become the default form of wealth owned by agents when considering how to allocate their income.

Money-capital is the ultimate form of liquidity⁸ in its area of circulation, and is favoured by

8. Clower famously said money was liquidity *par excellence*.

agents for this. Because of uncertainty, money-capital is at the same time an instrument better suited than any other as a medium of exchange although not essentially different from other instruments of wealth, and essentially different from other instruments as the ultimate form of liquidity and hedge against uncertainty. This is the essential problem of money in the wake of uncertainty. It cannot be solved. Because money is liquidity, it is the best suited medium of exchange and vice-versa. It is therefore logically impossible to conceive two instruments which could be as good as money to perform both tasks without being only one instrument.

Because of uncertainty, a more than rational share of capital is owned by agents as money capital and it is this share, linked to precaution and the desire for liquidity, that should be called savings. As Keynes (1936) showed, neoclassical economists are right to argue that over a given period of time investment and savings are identical in mathematical terms ($I \equiv S$). There is no need to make a conceptual difference between the two as today's savings are tomorrow's investments, savings are merely delayed investment (temporary disservice to money capital⁹) and both are embodied in projects yielding income.

If there is uncertainty, then end-of-the-period savings will be determined by beginning-of-the-period investment even if both end up being equal ($I = S$). Uncertainty creates the famous Keynesian "leak", which in Fisherian terms would be money-capital providing only the service of hedging against future uncertainty. However, this fund of money-capital does not guarantee a continuous flow of service as by definition under uncertainty the agent cannot know how big the fund needs to be to provide this same service of liquidity in the next period. Reduced uncertainty therefore reduces the leak and puts more wealth to productive use, raising investment and savings.¹⁰

Uncertainty and the concept of liquidity provides a serious challenge to the treatment of risk presented by Fisher. It leads Hicks to discard the concepts of saving and income altogether on a theoretical basis.¹¹ The concept of capital was limited afterwards to the narrower produced capital, characterised as one of the many potential factors of production. Controversies about capital were not over though, being reignited over another important feature of capital theory, the current and inter-temporal fungibility of capital items. This debate would be known as the Cambridge/Cambridge controversy.

The Cambridge-Cambridge controversy is a theoretical argument between mostly Keyne-

9. The careful reader would note that savings refer to both the disservice to money capital and money capital predestined for future investment. This is again not a problem when $I \equiv S$, but otherwise outgo to money capital should be termed differently.

10. An ironically quite Keynesian argument to shore up "confidence" in times of crisis.

11. Although we will see in the chapter 1 that the appeal of Hicks' type 1 income as an operational tool will endure and the concept be used in the subsequent literature.

sian economists in Cambridge, UK and mostly neoclassical economists in Cambridge, MA. A summary is presented by [Cohen and Harcourt \(2003\)](#). It involved the most famous names in economics at the time, such as Piero Sraffa, Joan Robinson, Paul Samuelson and Robert Solow. The first part of the controversy had to do with productive combinations and the idea that not all combinations of factors are equivalent. What is of interest in the controversy to our topic is the second part, exemplified by the observation from Joan Robinson reported in [Cohen and Harcourt \(2003\)](#) that there is a difference between difference and change. The process of accumulation cannot be described by merely comparing two steady states, by using an exercise of comparative statics.

The idea that a system would converge to equilibrium was quite alien to the Cambridge, UK side of the controversy. [Hicks \(1946, chapters IX and X\)](#) made a similar point. According to [Cohen and Harcourt \(2003\)](#) the controversy ended by the de facto victory of Cambridge, MA as empirical evidence at the time was broadly supportive of the neoclassical functions, although the theoretical points made by the Cambridge, UK side could not be overthrown. Evaluating the consequences of the controversy are beyond the scope of this thesis, but it is important to mention as it gives elements of context. As the nature of capital was still debated and the Keynesian and neoclassical conceptions of capital were about to diverge, capital theory was about to be put to new use.

The Meadows report from the Club of Rome ([Meadows et al. 1972](#)) was the first of a series of efforts to assess the impact of the new concerns for the environment on the economies of the world. Before the report, the debate about nature in economics was framed by the division between preservationists and conservationists. Conservationists wanted to preserve the environment for the sake of its services, a direct use through the extraction of resources and amenities (as for example in national parks). Preservationists wanted to preserve “primal” nature without relation to human needs and wants. The notion of “the environment” is quite complex and no single common definition exists in economics, let alone between disciplines. The term is old, but came to be characterised mostly by the *objects* of study and the *finality* of the study. [Theys \(1993\)](#) distinguishes between three conceptions of the environment: objective and bio-centric, subjective and anthropocentric and technocentric.

In economics, the second definition is favoured as the environment is usually defined with reference to human needs and activities. The environment becomes the purveyor of natural resources (renewable and non-renewable exhaustible resources) organised in ecosystems which provide useful services. Those services are threatened by the scope of human activities which may undermine the functioning of ecosystems, either via direct physical appropriation of territories, or via pollution. The Meadows report intended to raise awareness on the limits of

natural resources reserves, some of them critical to human industries. Reserves were evaluated in physical terms and ignored the economic mechanism organising exhaustible resources management. Since at least [Hotelling \(1931\)](#) exhaustible resources have been analysed as a form of capital. Resources could be optimally managed and integrated in the production process, just like labour and produced-capital. In their seminal book in 1974 [Herfindhal and Kneese](#) define capital as “anything which yields a flow of productive services over time and which is subject to control in production processes” ([Herfindhal and Kneese 1974](#), p. 68).

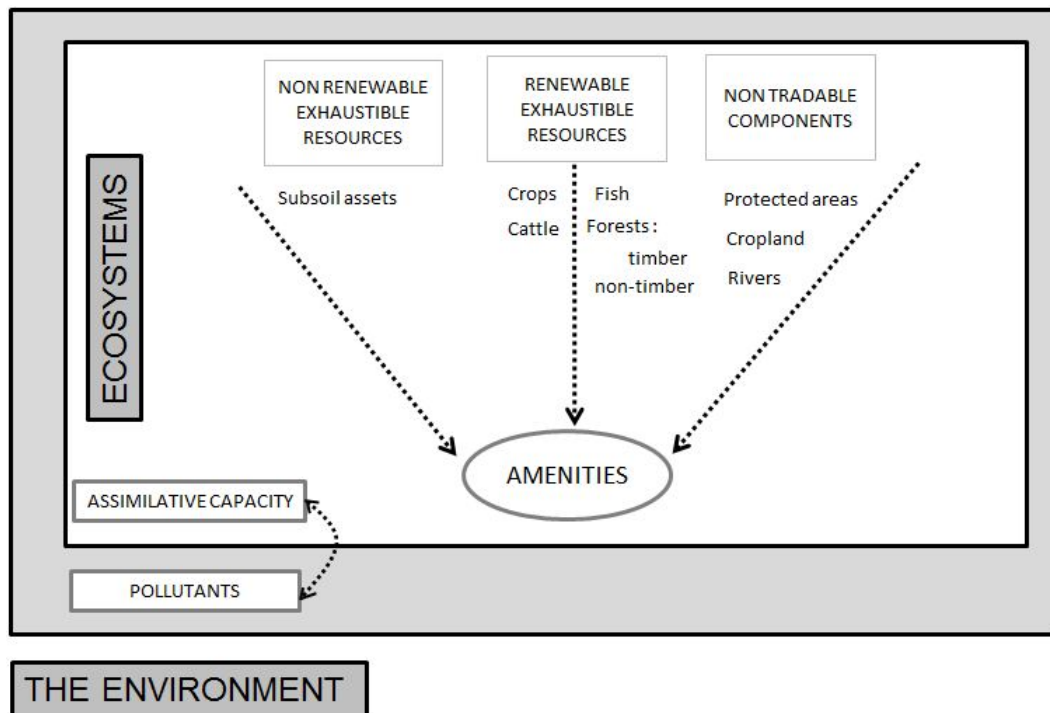
This definition, although restoring the “flow of services” flavour of the Fisherian definition, falls short of embracing consumer goods and makes no mention of it. It also puts an emphasis on productive services, de facto excluding ecosystem services that are not (yet) perceived as productive. But this definition paved the way for the extension of capital theory to address environmental concerns. The direct purpose of this enlarged definition is to take into account the growing role of the environment in the economy. Using capital theory is a way to “set a price” on the environment, either its direct contribution through natural resources, or through the services it provides via ecosystems. Natural resources were not considered to be valuable as they were not scarce (see the role of scarcity in neoclassical economics in [chapter 1](#)). Environmental economics specialises in dealing with pollution as a by-product of the relationship between humans and their environment. Resource economics studies the efficient management of exhaustible resources.

The challenge for economics is to provide a way to reveal the “real value” of resources that are either undervalued or not valued at all and therefore subject to overuse or pollution. [Herfindhal and Kneese \(1974\)](#), [Dasgupta and Heal \(1979\)](#) and [Solow \(1986\)](#) (see [chapter 1 section I](#)) completed the treatment of capital theory in a resources and the environment context. Finally, empirical applications were conducted on the basis of capital theory ([Repetto et al. 1989](#), [Pearce and Atkinson 1993](#)), when following the Brundtland report ([World Commission on Environment and Development 1987](#)) sustainability emerged as a field of enquiry.

The notion of natural capital was coined to describe the instruments of wealth in the environment, namely exhaustible resources and the ecosystems containing (and providing shelter to) them (see [figure 3](#)). The list bears resemblance to the instruments of wealth in [figure 1](#). The critical contribution from natural capital lies in the introduction of elements that are not valued, but are critical to the proper functioning of natural resources, such as pollination.

It is interesting to note that when capital theory was described by Fisher, capital had a broader and more accurate definition. Reading the contemporary definition of capital in empirical estimates such as those of the [World Bank \(2006, 2011\)](#), it is obvious that after the controversies of the 20th century about capital, sustainability is coming back to a vision of

Figure 3: The Environment and its components



Source: Author

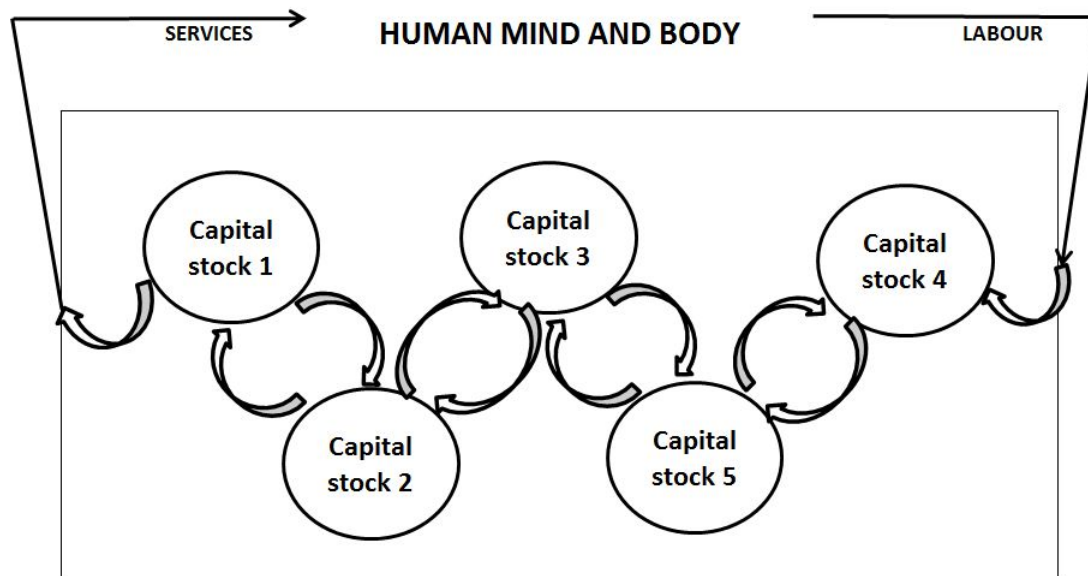
capital much akin to Fisher's.¹² But the loop is not completely closed, mostly because, as presented in chapter 1 section I, the contemporary value theory associated with capital theory in sustainability draws from Hicks (1946) and Hicks already started to diverge from Fisher.

We would argue that based on Fisher's theory of capital an internally consistent theory of capital is still possible. It is not only possible but it is probably a way out of the current controversies regarding sustainability. In this theory income is still the sum of the services provided by an agent's instruments of wealth. Consumption is the share of those services that is converted over the period as disservices to the human body (through a temporary transformation into money-capital). Investment is the beginning-of-the-period disservices to instruments of wealth.

A difference that is conceptually meaningless but operationally useful can be drawn between "replacement investment" to compensate the wear and tear of the instruments and investment into new (in the sense of not previously owned by any agent) instruments. If that distinction is drawn, then total investment should be (and will be, see chapter 1 section I) named comprehensive or inclusive investment. As for savings, we would favour its use to be limited to the share of money-capital that is owned for the service of liquidity for the sake of clarity. The rest

12. Inclusive income in Pemberton and Ulph (2001) is remarkably close to the Fisherian perspective.

Figure 4: The production process in capital theory



Source: Author

is indeed investment in one instrument or the other.

Neoclassical theory sticks to the idea that all of money-capital is destined to a different use than other forms of capital. So entrenched is this idea that in the remaining of this work “savings” will be used to refer to money-capital owned by agents to provide disservices in future periods to other instruments. And in that sense, the share of money-capital that is not owned to address liquidity issues is equal to comprehensive investment. In figure 4 we show how the production process can be understood as a chain of instruments of wealth organised around outgo from the human mind (via his body, called labour) to bring back income to human beings.¹³

This is the final complexity attached to capital theory. Capital theory clearly illustrates how the concept of value is meaningless out of any references to humans. Capital theory can only help in setting rules for human/environment interactions under a set of values defined by human beings. We presented capital theory and the critical concepts of wealth, capital, income and investment. Capital theory provides a theory of the relation between human wants and needs and the means available to satisfy those. It is now time to turn to the theory of means allocation and valuation used to form the basis for the theory of sustainability, namely utilitarianism.

13. Income and outgo are used here from the pool of instruments of wealth perspective.

I.2 Value and sustainability

In *The Nature of Capital and Income* Fisher considers value to be simply price times quantity, both being expressed either in monetary or physical units. Fisher describes an economy where wealth is given and needs and wants are exogenous. From an operational perspective capital theory works well in describing how human needs and wants can interact with the inert and living matter. Still, his theory lacks an allocation mechanism to explain how exchanges are organised and decisions regarding the satisfaction of needs and wants are taken.¹⁴ As it is well-known, the neoclassical theory of utility provides such an allocation mechanism.

The question of the source of value is probably the oldest in economics after the question of the nature of wealth. Intuitively value should be associated with the needs and wants of human beings and therefore be the *raison d'être* of economic activity. But as presented by Fisher, humans are on both sides (“loose ends”) of the economic system (see figure 4). Agents are the final recipients of services, but also the providers of the sole disservice not instantly matched by a service: labour. Fisher agrees with Jean Bodin (1576) saying “Il n'est de richesse que d'hommes”. Value and wealth both being sourced in human beings, value can either emerge from needs and wants or labour. We saw earlier that the Physiocrats saw in land the sole source of value. Land as a source of value was deemed unacceptable as it did not recognise the value generated by the expanding manufacturing sector.

Later, Smith (1776) expanded the sources of the “Wealth of Nations” to include manufacturing. The source of value moved from land to labour. Smith (1776) and Ricardo (1817) assumed that value was generated as labour was added to the production process. Labour was at first perceived as a good standard for value, especially as Smith claimed it could solve the famous diamond-water paradox. Economists have also made an early difference between value in use and value in exchange. Value in use is the subjective value of an instrument for the agent using it. The value in exchange is the amount of instruments an agent can obtain against the element he is offering. For Smith, labour solved this problem as the price a man was ready to pay for an element is “the toil and trouble of acquiring it” (Smith 1776). The labour theory of value failed however to explain the fact that some elements requiring less effort to collect or assemble could prove more valuable than elements requiring more.

Finding how value is determined supposed from the start a theory for the motivation of individuals, for the relationships between individuals, and potentially for the relationships between an individual and a group, and a group and a larger group. The subjective theory of

14. Fisher refers to the works of Jevons (1871) and Walras (1874) and states that individuals will satisfy needs and wants from the more pressing to the less pressing. But he does not propose a link between those elements (he presents as obvious) and his theory of capital.

value states that the value of things is in direct relation with agents' wants and needs. Economic agents are defined as members of a society, characterised by rational thinking and an ability to rank goods and services according to their preferences. An economic agent can either be able to attribute a value to the satisfaction derived from the acquisition and consumption of one good (cardinal preferences) or be able to rank the acquisition of those goods on a scale (ordinal preferences). An element that is neither wanted nor needed by agents (or ranks low on the scale of needs and wants) will have low value.

This opposite is true for an element that ranks high on the scale. From the recognition of the subjectivity of value comes the theory of utility and the concept of marginal utility. Utilitarianism, sometimes called "Benthamite utilitarianism" in reference to Jeremy Bentham (1748-1832) to differentiate it from close but different philosophical traditions, is the basis of the theory of utility.¹⁵ Utilitarianism views man as rationally reacting to pleasures and pains.¹⁶ Bentham (1789) famously equated usefulness with the production of pleasure and avoidance of pain. In this view, the difference between needs and wants is rather artificial: both are evaluated depending on the pleasure generated by satisfaction and pain generated by the non satisfaction of both.

If an agent has the possibility to choose between several elements to acquire, he will acquire first the one that satisfies the most pressing need or want. If that need or want is satisfied he will move on to the next one. If not, the agent will acquire again the element satisfying the same, as of yet unsatisfied, need or want. The concept of marginal utility was proposed simultaneously by Jevons (1871), Menger (1871) and Walras (1874) to describe the small increment to utility brought by the consumption of an extra good or service generating pleasure. Marginal utility is decreasing as more units of the same goods are consumed, therefore total utility is growing at a decreasing rate as consumption increases.

The theory of marginal utility therefore assumes both the ability to rank elements according to preferences and the ability to attribute a quantity to the satisfaction of a given need or want. If the agent can only rank, it is impossible to decide when to stop acquiring and using a given good. If he can only estimate the required quantity of an element to satisfy one need, he cannot compare two different elements that may satisfy two different needs. This problem was raised by Hicks (1946, see Chapter I) who advocated against using marginal utility as it seems dubious that agents can attribute a number to a given level of utility. Only the ratio of marginal utility (the rate of marginal substitution) which represents ordinal utility should be used. But regardless of this problem, marginal utility is still used today. The use of the word

15. Dasgupta (2001) calls this form "classical utilitarianism".

16. Bentham proposed a list of pleasures and pains and tried to produce hedonistic indicators of social welfare based on those.

utility to describe the pleasure generated by the consumption of goods and services was also criticised, as early as the works of Vilfredo Pareto, who suggested to use *Ophelims* instead. The words *felicity and desirability* have also been proposed. But no other concept proved compelling enough to overthrow utility.

Whether ordinal or cardinal utility, increased consumption raises utility but greater quantities are required to raise utility by the same amount because of decreasing marginal utility. Conversely, something that is supplied in little quantities will have a higher marginal value. With this brilliant intuition, utility theory put at the centre the concept of scarcity: subjective value is associated with items that are relatively scarce as their marginal utility will be higher. We can not stress enough that the theory of utility is based on relative scarcity: the agent has to choose between elements that are more and less desirable and more or less scarce.

The analysis of utility is, as is well known, usually conducted with “well-behaved” functions.¹⁷ Utility is asymptotically convergent, and therefore ill-equipped to describe situations of absolute scarcity (when the supply of consumption goods is absolutely scarce, as in famines) or absolute abundance (when the supply of consumption goods is disproportionate compared to the needs and wants as with the cornucopia).

The theory of utility and the concept of scarcity are the foundation of the neoclassical theory of value. First popularised by Marshall (1920) the theory of utility is the basis of the constrained optimisation and general equilibrium analysis which are the workhorse tools of neoclassical economics. Based on the theory of utility Lionel Robbins famously characterised economics as “the science which studies human behaviour as a relationship between ends and scarce means which have alternative uses.” (Robbins 1932). In reaction to the Keynesian revolution, which describes the economic system without reference to a theory of value, Arrow and Debreu (1954) introduced a formulation of the general equilibrium model still in use today.

There is obviously interdependence in the development of the concepts used in economics. As we saw earlier with capital theory, it is possible to develop a theory of means without actually defining any allocation mechanism. Conversely, it is possible to imagine a theory incorporating general equilibrium analysis but not capital theory. In the neoclassical theory, the allocation mechanism is based on the theory of utility as described by the utility function. The general equilibrium analysis is based on markets.

Together, those theories would grant an optimal allocation of all the resources available, as expressed in the equilibrium conditions (or market clearing conditions). A general equilibrium

17. Satisfying the Inada conditions: the function is continuously differentiable, strictly increasing, concave, $f(0) = 0$, $\lim_{x_i \rightarrow 0} \frac{\partial f(x)}{\partial x_i} = +\infty$ and $\lim_{x_i \rightarrow \infty} \frac{\partial f(x)}{\partial x_i} = 0$.

is a situation where all markets are in equilibrium: all the exchanges that could improve the utility of one agent without decreasing another's (Pareto-optimality) have taken place. In this state of the economy, "the greater good for the greatest number" to borrow the famous sentence of Joseph Priestley; is granted *under the constraint of the original allocation of resources*. The famous second theorem of welfare economics shows that any Pareto-optimal outcome can be reached granted that the correct original distribution of resource can be arranged via lump-sum transfers.

Those are the building blocks of mainstream economic analysis. The [Meadows et al. \(1972\)](#) report then brought forward the need to consider potential limits to growth, which would in fact result in upper-limits to achievable individual utility. Proponents of this approach draw from environmental and ecological studies to propose an alternative economic model.

I.3 Ecological economics and strong sustainability

[Marshall \(1920\)](#) cited by [Victor \(1991\)](#) reminds us that "land is a permanent and fixed stock while appliances made by man... are a flow capable of being increased or diminished...Now if the nation as a whole finds its stock of planing machines or ploughs inappropriately large or inappropriately small, it can redistribute its resources. It can obtain more of that in which it is deficient, while gradually lessening its stock of such things as are superabundant: but it cannot do that in regard to land: it can cultivate its land more intensively but it cannot get any more". Although Marshall seems to be confusing the flow of services generated by appliances with the stock of it (and therefore ignoring any sunk cost for example) he makes a point about the difference in nature, beyond the debate of physical substitutability. Although land (part of natural capital) can potentially be cultivated more extensively (suggesting imperfect substitution with man-made capital) the total surface available is limited (ruling out imperialistic behaviour and international trade for now).

When Nicholas Georgescu-Roegen published *The Entropy Law and the Economic Process* in 1971 his intention was to show how the evolution of thinking in physics, statistics, mathematics and biology had consequences for economics as well. More than half of his book is devoted to the presentation of concepts from those disciplines and only the remaining part to economics. [Georgescu-Roegen \(1971\)](#)'s main argument is made using the concept of entropy. Instead of focusing on time, economists should see the evolution of economics as the transition from a state mostly characterised by low-entropy materials to a state of high-entropy materials. Economics he argues, still uses laws akin to the principle of Newtonian classical mechanics, but the law of thermodynamics (and especially the entropy law) shows that economic systems cannot be

described by comparative statics. There is no “coming back” to a previous state of the system as entropy (understood as energy dispersal) prevents this.

Economic processes should be described as a set of physical flows using low entropy materials (such as fossil fuels) and generating high entropy materials (such as waste). The point about comparative statics clearly echoes the point made by Joan Robinson in the Cambridge/Cambridge controversy: change and difference are two different things. But it has an even more direct implication. If any step of a given production process is in essence an evolution from low entropy to high entropy, then there is no equivalence between a state of the world 1 with 10 units of iron and 5 units of machines and a state 2 with 10 units of machines and 5 units of iron. Although the value (expressed in any given unit) is constant, the overall entropy in the system increased while moving from state 1 to state 2. From a physical perspective, the two states are by no means equivalent. A detailed analysis of the consequences of the second law of thermodynamics is available in [Ayres \(1998\)](#).

Although the book is contemporary to the debates surrounding the [Meadows et al. \(1972\)](#) report, it was largely ignored until the end of the 1980's. The direct implication of Georgescu-Roegen's principle of entropy is that fungibility in capital as proposed for example by the Hartwick rule (see chapter 1 section I) is an illusion. There is no substitution possible between one instrument of wealth and another, there are only transformations and increasing entropy. [Georgescu-Roegen \(1971\)](#)'s ideas were completed by his student and friend Herman Daly, who tried to introduce the concept of carrying capacity into mainstream economics.

[Daly and Cobb \(1989\)](#) and [Daly \(1996\)](#) questioned the ability of a geographic area, characterised by ecosystem services provided and resources available, to support more than a given number of human-beings and a given degree of activity (or way of life). Ecosystem services are the flow of services provided by a community of living organisms and their environment. Some of those services, such as air recycling and water filtration are critical to human life and are to be delivered by man-made alternatives to the adequate scale. Ecosystems are more than the sum of their individual components, and although the services of individual components can be comprehended by markets as those components are material and can be owned (and are therefore capital), the services of the whole ecosystem are typically a positive externality, a total contribution greater than the sum of the parts.

Under such critical externalities the set of real world markets is neither efficient nor optimal. Those concerns about externalities were handled by pushing for a general extension of the scope of market activity, notably by the development of cap and trade systems, locally and globally. If the failure of market mechanism was related to transactions costs and externalities, then a push to reduce transaction costs and an “internalisation of externalities” should be able to solve

the problem. This is the beginning of contingent valuation using Willingness To Pay (WTP) and Willingness To Accept Compensation (Hanley et al. 2001). In the famous 1997 article in *Nature*, Costanza et al. (1997) estimate the value of ecosystem services to lie within a range of sixteen to fifty-four trillion of dollars per year.

Several options for the proper management of ecosystems have been proposed, from complete conservation to multiple use management (Swallow 1996). More generally, proponents of ecological economics tried to introduce concepts from physics and biology into economics and political science.¹⁸ Following Georgescu-Roegen (1971)'s contribution, they point at rapid methodological advances in natural sciences that never were translated in social sciences.

Following the works of Daly, a second journal that would give its name to the field was launched, *Ecological Economics*. The main concern of ecological economics as a discipline is "strong sustainability" as opposed to "weak sustainability". Proponents of strong sustainability defend the principle of non (or at least very limited) substitutability between different instruments of wealth. There is therefore a possibility of absolute scarcity, if a critical form of capital come close to depletion.

When assessing sustainability, how to translate the constraints of absolute scarcity? In other words, how to manage resources that are or will become strategic assets? Is the national or global level relevant? Is the general carrying capacity of the environment to be considered at the same level as strategic assets? What are the drivers of carrying capacity and which policies should be implemented to encourage people to develop it and reduce incentives to decrease it? More generally, can non market mechanisms work well next to market mechanisms? Ecological economics registers as an heir of a long tradition of holistic approaches in economics, from the Physiocrats to Institutionalism.

Ecological economics wrestles with the problem of matching biological, physical constraints regarding natural reproduction and evolution on the one hand and maintenance of a resource with respect to human needs and wants on the other hand. Ecological economics is quite successful at proposing analytical tools for defined (i.e. limited) problems, the most high-profile one being the ecological footprint (Wackernagel and Rees 1996, Wackernagel et al. 2002). But it failed as of today to identify a mechanism akin to neoclassical economics' markets. A more detailed presentation of the debate between weak and strong sustainability can be found in Neumayer (2010). The question of the actual level of substitutability, although the main bone of contention here, has not been resolved yet.

18. In a different context Hobsbawm (1994) saw some application in social sciences for Bohr's principle of complementarity.

It should however be noted that studies addressing the issue found a high degree of substitutability (Markandya and Pedroso-Galinato 2007) between natural and produced capital.¹⁹ It is an empirical question that is difficult to tackle. The World Bank (2006) used its wealth estimates (see chapter 1 section I.2) to test the current level of substitutability between exhaustible resources and produced capital. The report shows a fairly high number, around 80% of actual substitution. Proponents of strong sustainability would eagerly respond that should it be true, it only shows substitutability in the present and eventually the past and is no guarantee of future substitutability.

Substitutability is in essence a dynamic notion. Evolutions in technology, demography, tastes can make some forms of capital strategic at some point (or in some places), but not for any time or places. A commonsensical approach would be to shield strategic assets from depletion by the implementation of “safe minimum standards”(Pezzey and Toman 2002). The preservation of option values, such as biodiversity should also be undertaken. Biodiversity is an indicator of the health of ecosystems and a potential tank of benefits for mankind as scientific progress discovers the potential for complementarity or symbiosis with the rest of the biosphere. Industrial ecology (see the famous example of Kalundborg) is the perfect example of environment-inspired human organisation.

The weak sustainability paradigm following Hartwick (1977) argued for a central object for sustainability, savings (see chapter 1 section I). Strong sustainability still favours multiple targets and keeps debating about the meaning of sustainability (Baumgärtner and Quaas 2010, van den Bergh 2010). Victor (1991) distinguishes between four types of maintenance for capital: physical quantity, total value, unit value of the services and value of the resource flow. Costanza and Patten (1995) argue for different time scales and scope of sustainability depending on the service considered. The debate is still open and is very much alive.

A final note should be made that most of the literature is concerned with the supply side when it comes to sustainability: how to provide for the wants and needs? The answer to this question is largely related to the evolution of the wants and need, the pattern of consumption. For a given trend in technical progress, it is obviously always easier to accommodate a lower level of consumption. The social dimension of consumption and the possibility of over-consumption are explored by Jackson (2007). The consumption side potentially plays an empirical role as well in the calculation of factor contributions.

This final note on consumption ends our presentation of the basic concepts of sustainability: capital theory, the theory of value and weak versus strong sustainability. Those questions have

19. And also that many ecological economists would object to the very notion of “natural capital”.

been addressed in an already very large body of literature. However, most sustainability studies are performed in the national context, or even at the ecosystem level. It is at the same time quite clear that the sustainability challenge, although more or less acute in different areas of the globe, is in essence a global challenge. Nothing illustrates this point better than global warming and ocean acidification. It seems therefore legitimate to put the sustainability question in the context of international exchanges, cooperation and competition. It could indeed be argued that the broad environmental question and the current phase of globalisation are the two salient global changes of our time.

II Sustainability in an era of globalisation

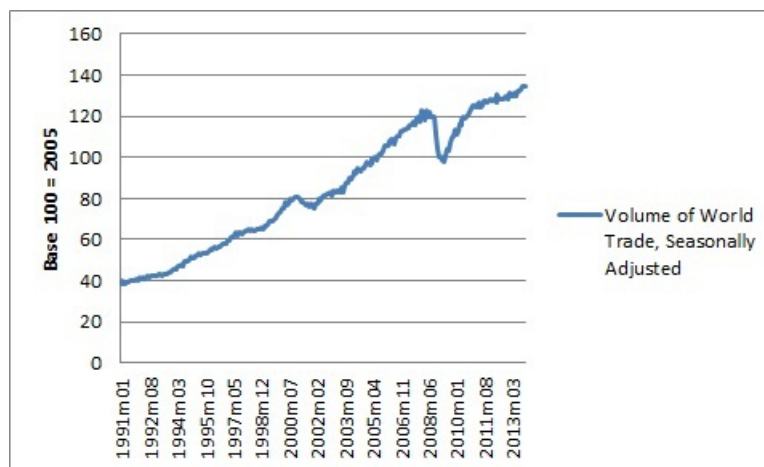
International trade analysis covers many different elements: goods and services, capital exchanges, financial flows, preferences and spillovers. The field is usually divided between the study of open economy macroeconomics, focusing on exchange rates, financial flows and macroeconomic imbalances, and the field of plain international analysis, focusing on merchandise, capital goods and service trade. Another way to see those functions is to discriminate between international trade and open economy studies. International trade is then the study of trade relations, observable or predictable trade flows (i.e goods, services, capital goods, financial flows) and the domestic economic pattern that might be responsible for those flows. Open economy macroeconomics and tradestudies the transition from an autarky setting to an economy that starts to have relations with other economies.

The first approach usually generates prescriptions for the organisation and the management of international trade and presents the interaction between trade flows and domestic factors. It also studies the structure of trade and trade relations in a dynamic context. The second approach takes trade flows and dynamics as they are and merely reflects the consequences of the state of international trade on domestic economies. To put it in another way, one can either take international trade as given and adapt to it, or one can study the evolution of international trade as the result of evolution in domestic economies.²⁰ In economic literature studies of international trade and sustainability have long been viewed as separate exercises.

International trade was concerned with the efficient allocation of goods and capital, contributing to sustainability via productivity improvements and increased welfare for a given level of production. Proponents of strong sustainability first criticised this assertion, arguing that international trade is not a “neutral” mechanism to improve global efficiency. [Daly \(1996\)](#) ar-

20. The distinction obviously holds in partial equilibrium analysis. In comparative statics general equilibrium, both trade flows and countries are altered.

Figure 5: The volume of world trade since the end of the cold war



Source: CPB World Trade Monitor, Netherlands Bureau for Economic Policy Analysis, 2014

gues the conclusions of neoclassical theory are flawed as capital is now mobile internationally, when the logic of the comparative advantage is based on international factor immobility.

There certainly is an important increase in the volume of merchandise trade since the second world war, particularly since the fall of the Soviet Union (see figure 5). This is usually compared to the first globalisation from the 1875-1914 period, an age the historian Eric Hobsbawm characteristically calls *The Age of Empire*.

Phases of globalisation are more than “simple” phases of trade expansion. They are characterised by global dispersion of innovation, a new international division of labour, increased labour mobility as well as an increase in trade flows. The analysis of international trade has followed those evolutions in the nature of trade and several models have been proposed to explain the existence and the development of trade, trying to predict the consequences of further trade expansion. More recently, the “new trade theory” proposed a new modelling strategy to explain patterns of trade in a global context.

II.1 International trade expansion: the logic of comparative advantage

After the mercantilist phase, the emerging classical school developed the notion of comparative advantage. Smith (1776), then Ricardo (1817) presented respectively the idea of the absolute and the relative comparative advantage. A comparative advantage is an advantage given in a country, that forms the basis of trade. The country should specialise into the pro-

duction of goods in which it has a comparative advantage and enter trade to acquire the other goods, to obtain the greatest benefits for exchanging nations. Note that the division of labour and the resulting specialisation within and between countries form the rationale for trade. In [Smith \(1776\)](#), the advantage is absolute. Countries specialise in goods in which they are *absolutely* more productive than other countries.

The great innovation of [Ricardo \(1817\)](#) is to show that even if one country has an absolute advantage in every goods, trade is still interesting if the country with all the absolute advantage entrusts the production of the goods in which the other country is the least disadvantage to this very country. Country *A* possesses a comparative advantage in producing good *X* when its opportunity cost of producing *X* is lower than its trading partners'. The notion of comparative advantage establishes that for a given set of countries, specialisation and trade generates welfare gains that exceed autarkic possibilities ([Leamer 1984](#)). Theory predicts that small open economies specializing according to their comparative advantage exhibit an increase in overall efficiency, face lower real prices for consumption goods, and experience net welfare gains ([Deardorff 1980, 1982, 1994a](#)).

Over time, several sources of comparative advantage were uncovered, but the main ones are:

- Productivity differences due to differences in knowledge and technology ([Dollar 1993, Dornbusch et al. 1977, Eaton and Kortum 2002, Treffer 1995](#)).
- Differences in factor endowments resulting in different specialisations ([Deardorff 1982, Leamer 1993, 1995, Ohlin 1933](#)).
- Differences in the number of varieties produced and in the size of the internal market ([Chaney 2008, Krugman 1980, Melitz 2003](#)).
- Differences in the property rights regimes, in legislation and overall institutional quality (notably enforcement of laws and standards) ([Chichilnisky 1993, 1994](#)).
- International increasing returns to scale resulting in trade in intermediate products ([Ethier 1982](#)).

Studies of international trade based on increasing returns to scale distinguish between internal scale economies, sourced in fixed costs, and external scale economies, emerging from agglomeration forces and resulting spillovers. Due to its simplicity, parsimony, and apparent explanatory power, the logic of comparative advantage drives much of the literature on international trade. The first model based on the work of Ricardo is the Ricardian model: international trade is explained by productivity differences. Some countries are able to produce more of a given good than others with the same amount of capital.

Starting with the works of [Ohlin \(1933\)](#), a second source of comparative advantage was

explored after the first world war and the end of the first globalisation period (The “Age of Empire” following [Hobsbawm \(1994\)](#)). The Heckscher-Ohlin (HO) model explains the development of international trade by the asymmetric distribution of factor endowments across countries. In its basic 2-2-2 form, the H-O model consists of 2 countries, each endowed with 2 factors (inputs), which can be used to produce 2 tradable goods. Also known as factor proportion models, HO models emphasize differences in factor endowments as key determinants of trade relationships.

They entail several simplifying assumptions: technology is constant across countries, production functions exhibit constant returns to scale, factors are mobile within countries (and domestic industries) but immobile between countries, all agents are price takers, and factor endowments may differ across countries. Notably, many of these assumptions eliminate alternative sources of comparative advantage. The original HO model gave rise to four major theorems:

Factor Price Equalization is both an assumption and a long run prediction, stating that *ceteris paribus*, international trade causes factor prices to equalize in the long run ([Baldwin 2008](#), [Leamer 1995](#), [Ohlin 1933](#)).

Heckscher-Ohlin Theorem under which countries endowed with greater environmental resources will specialize in and export environmentally intensive goods, *ceteris paribus* ([Copeland and Taylor 2003](#), [Deardorff 1980, 1982](#), [Neary and Schweinberger 1986](#)).

Stolper-Samuelson Theorem . In the HO world, a rise (resp. fall) in the real price of good X yields higher (resp. lower) returns to the factor in which X’s production is most intensive ([Feenstra 2004](#), [Jones and Scheinkman 1977](#), [Stolper and Samuelson 1941](#)).

Rybczynski Theorem . An increase in the supply of the factor in which good X is intensive will lead to a more than proportionate increase in the output of good X, assuming goods prices are unchanged ([Rybczynski 1955](#)).

As clearly stated by the Stolper-Samuelson theorem, HO-type trade creates potential competition between factors, for the benefits of countries. Factors benefit from increases in the price of the goods when production requires them intensively and vice-versa. [Vanek \(1968\)](#) extended the original 2-2-2 model to n-dimensions. The four theorems carry unscathed from this operation, apart from the Stolper-Samuelson theorem which is reduced to a telling “friends and enemies” version.

In this n-dimension version of the theorem, every factor has a good which is a natural enemy and a natural friend²¹. It is however not possible to pin down those goods because of

21. A good is a natural enemy of a factor when an increase in the price of this good lowers the income of this factor. Conversely, a good is a natural friend of a factor when an increase in the price of this good increases

the dimensionality problem. [Deardorff \(1982\)](#) proposes a general demonstration of the validity of the comparative advantage²².

The first empirical test of the HO model was conducted by [Leontief \(1953\)](#) in what is remembered as the “Leontief paradox”. Quite strikingly, Leontief shows that the United States export labour intensive goods, when capital intensity was expected. The puzzle was later explained by differentiating between qualified and unqualified labour. The United States were in fact relatively well endowed in qualified labour. Another potential explanation lies in the necessity, shortly after the second world war, for the United States to produce goods that were not yet produced by any potential trade partner. This finding is in line with the statistics on comprehensive wealth showing that the great majority of developed countries are relatively well-endowed in human capital (see figure 6).

Since then, several empirical tests have been conducted on the Ricardian and Heckscher-Ohlin models of trade. Those tests confirmed that the predictive power of the HO and Ricardian model were relatively low, slightly better than a toss of coin ([Leamer 1984](#)). [Trefler \(1993\)](#) observed that the volume of international trade was only a fraction of what could be expected from trade theory. To explain this “missing trade”, he proposed an Heckscher-Ohlin model where technology matrices would differ across countries, effectively combining a test of Ricardian and HO trade. This transformation greatly improved the predictive power of the model, compared to the test realised by applying the United States technology matrix to all the trading partners. Later tests under increasing returns to scale ([Antweiler and Trefler 2002](#)) and accounting for factor price equalisation violations ([Debaere and Demiroglu 2003](#)) also improved the predictive power of the canonical models.

The first analytical juncture between the trade literature and the emerging sustainability literature occurred in the first five years of the 1990’s. Following the first Rio Earth summit, potential damages to the environment from economic development came on top of the agenda in several fields. As far as international trade is concerned, it is the negotiations surrounding the North American Free Trade Agreement (NAFTA) that brought into light the potential spillovers between the two fields. Concerns were raised that the NAFTA would probably bring economic gains in line with the logic of comparative advantages, but at the cost of environmental quality. Competition from Mexican producers would lead to a downward pressure on American environmental standards. In their seminal working paper ([Grossman and Krueger 1991](#)) and article, [Grossman and Krueger \(1995\)](#) suggested that free trade was overall the best option because of the likely existence of an Environmental Kuznets Curve (EKC).

the income of this factor.

22. For a general review of the HO models and the n-dimension extensions see [Baldwin \(2008\)](#).

Figure 6: Intangible Capital in OECD countries

Panel B	OECD	Non- OECD	Year	Year	Year
			1995	2000	2005
	Means (standard deviations in parentheses)				
Total wealth	486,177 (183,435)	61,000 (84,088)	157,722 (204,314)	162,365 (213,149)	169,751 (229,400)
Produced capital	90,562 (34,932)	11,566 (17,580)	30,153 (40,364)	30,237 (40,081)	31,410 (42,447)
Natural capital	17,656 (19,540)	10,102 (20,805)	12,050 (21,709)	12,947 (22,212)	10,806 (18,360)
Net foreign assets	-3,469 (15,814)	1,072 (11,083)	273 (11,537)	-165 (12,799)	-135 (13,120)
Intangible capital	381,427 (147,274)	38,260 (52,810)	115,246 (158,600)	119,347 (167,351)	127,669 (182,924)
Intangible capital/ total wealth	0.78 (0.06)	0.59 (0.18)	0.63 (0.17)	0.63 (0.19)	0.66 (0.19)
Years of schooling	9.64 (1.59)	5.53 (2.44)	5.99 (2.83)	6.61 (2.84)	6.88 (2.88)
Human capital	4.14 (0.57)	2.71 (0.71)	2.92 (0.88)	3.08 (0.90)	3.16 (0.95)
Rule of law	86.64 (10.12)	46.48 (16.92)	57.74 (24.25)	56.04 (22.52)	54.96 (23.06)

Source: Ferreira and Hamilton (2010)

The Kuznets curve is an inverted U-Shaped relationship between GDP per capita and inequality. The Environmental Kuznets Curve (EKC) postulates that as GDP per capita increases, pollution first increases until a given threshold and then decreases as better-off citizens demand higher environmental norms and quality. As international trade generates income gains, free trade agreements should have a positive impact on environmental quality. Following an early proposition of Grossman and Krueger (1991), Copeland and Taylor (1994) decompose the impact of trade on the environment into three effects: scale, technique and composition. Later tests of their theory (Antweiler et al. 2001, Copeland and Taylor 2003) show that the overall impact of trade on the environment is positive, at least for the selection of air pollutants used as proxies for environmental quality.

This favourable story of trade is tempered by the fact that gains from trade are rarely distributed evenly: some win while others lose (Dixit and Norman 1980). Also, if property rights are ill-enforced or ill-defined (Chichilnisky 1994) specialisation can be detrimental to the environment, often through over-exploitation of the commons (domestic and global), as is often the case in fisheries (Ferreira 2007, Ostrom 1990, World Bank and FAO 2009). However, as long as gains exceed losses, (potential Pareto) compensation is theoretically possible, and

trade can be considered a net benefit.²³ “Trade optimists” argue that greater production efficiency, technical progress, and tighter regulation driven by higher living standards benefit the environment (Neumayer 2001). “Trade pessimists” argue that theoretical assumptions break down in practice²⁴, and voice concerns that international trade fuels a potential “race to the bottom” in global environmental standards (Martinez-Alier 1995, Muradian and Martinez-Alier 2001).

Sides in the argument in the debate on the relationship between trade and the environment (optimists and pessimists) are usually a match to sides in the debate on strong versus weak sustainability. The optimistic message of the Copeland and Taylor model rests on restrictive assumptions regarding what actually is “the environment”. “Environmental resources” refer not only to stocks of exhaustible resources, fisheries, and forests, but also to air, water, and assimilative capacity. In particular, “assimilative capacity” may act as a euphemism for regulatory stringency: countries with strict pollution controls are in effect endowed with fewer environmental resources in that sense.

This confusion of physical endowments, assimilative capacity and pollution damage makes sense from the conceptual perspective of capital theory applied in environmental economics. It is obviously not viewed in a favourable light by proponents of strong sustainability. Nonetheless, as in the Cambridge/Cambridge controversy, the arguably rough analytical framework provided by international trade theory and environmental economics yielded useful insights. A good example of this is the pollution haven hypothesis. The Stolper-Samuelson theorem stresses competition in a globalised world is as much between factors as it is between firms and countries. Leamer (1995) uses this theorem to explain the downward pressures on wages in developed countries in the 1990’s. Similarly, a country could increase its factor endowment of environmental resources simply by reducing pollution regulation, triggering a “race to the bottom”.

This is the underlying mechanism behind the creation of pollution havens, clusters of polluting (usually heavy) industries located in developing countries. Pollution havens are opposed on ethical grounds: developing countries should not have to sacrifice their environment to attract industries, and developed countries should not have to sacrifice their higher standards on the altar of international competition. Whatever one’s opinion, the logic of pollution havens is effortlessly explained by both the HO model and the New Economic Geography. Pollution havens were even supported on quasi-libertarian grounds by economists such as Lawrence Summers²⁵.

23. Notably through the implementation of local management schemes, as is the case for fisheries in Iceland.

24. Daly and Cobb (1989) and Daly (1996) show how violating the assumption of factor immobility distorts the gains from trade.

25. In the famous “Summers memo” from 1991.

The logic of comparative advantage has been the main force behind trade expansion during the industrial revolution. It is still presented as the main mechanism behind successes in development strategies (Yi-fu Lin 2012). However, the canonical models failed to explain the rapidly emerging movement in inter-industry trade from the 1960's onwards. The very structure of trade seemed to change as the source of comparative advantages in a world characterised by stronger competition seemed to be increasingly challenged by the emergence of industrial nations in the formerly under-developed world. Intra-industry trade was the first symptom announcing a new phase of globalisation, based on the importance of agglomeration, market size and competition between factors. We will now present the changing nature of international trade in the current phase of globalisation.

II.2 International trade in the context of globalisation

The logic of comparative advantage in HO or Ricardian models is based on the international division of labour *between sectors*, either according to technology differences, or discrepancies in factor endowments. In a world of free trade, an exogenous increase in the number of goods should lead to an increase in the volume of trade. Such phases of *trade expansion* occurred frequently in history, as for example with the new products brought by the discovery of the Americas, the extension of the Venetian trade or the development of the silk route. Inter-industry trade booms made sense as they increased the number of goods and services available to consumers, usually by bringing them from afar.

Phases of globalisation change this logic as they are mostly marked by increased intra-industry trade (Grubel and Lloyd 1971). Globalisation describes a trend of increased interconnection and exchanges of all kind between countries and actors of international relations. It translates into the emergence of a common working language, common norms and standards used throughout the world, the spread of communities of interests and cultural communities transcending national barriers. Globalisation is therefore not only an economic phenomenon, it has political and cultural consequences.

Economic historians usually describe two phases of globalisation. A first phase starts with the end of the Franco-Prussian war of 1870 bringing relative peace to continental Europe and the beginning of the first world war in 1914. A second phase starts around 1973 with the official end of the Bretton Woods system of fixed exchange rates, accelerates with the fall of the Soviet Union and the incremental insertion of former communist countries in the global economic system²⁶, and goes on until today. On its economic side, globalisation is best described as the

26. As exemplified by the accession of China in 2001 and Russia in 2012 to full membership of the WTO.

emergence of two new realities:

- Multi-National Firms (MNF) which produce in different countries, calling into question the old model of the national firm with a national base.
- The expansion of trade in intermediaries, linked to the international division of production processes (IDPP).

A comprehensive presentation of those two developments can be found in [Berger \(2006\)](#). The IDPP is the deepest transformation, as it profoundly altered both the nature and the scope of the organisation of production factors in production processes. It alters organisation, in the sense that the combination of factors is now dependent on an international benchmark of potential combinations, realised depending on circumstances such as prices, legislations, point in time advantages such as subsidies, etc. It also alters the magnitude, as a wave of globalisation is systematically associated with the integration of new countries in global exchanges.

As new countries entered globalisation, new opportunity of IDPP emerge. The signature of the current globalisation is the emergence from 1990 onwards of new information and communication technologies which helped to level the playing field of the global factor competition. As presented in [Friedman \(2005\)](#) this “flat” playing field allows the efficient coordination of previously out of reach factors into global supply chains, managed by “core” MNF. In the current phase of globalisation, the key economic object is the global supply chain. The global supply chain is the logistical reality behind trade, the organizational pattern of flows in intermediate goods and business services managed by a reduced group of MNF responsible for transportation and assembly of most of today’s production.

International trade theory first perceived globalisation with the development of intra-industry trade. [Grubel and Lloyd \(1975\)](#) proposed an indicator, the Grubel-Lloyd index to assess this phenomenon (see chapter 4). Intra-industry trade takes root in economies of scale and learning-by-doing in human capital, which in turn generates monopolistic competition. [Dixit and Stiglitz \(1977\)](#) proposed a seminal model for monopolistic competition, which was then used by [Krugman \(1980, 1981\)](#) to propose an explanation for intra-industry trade based on the taste for variety. [Lancaster \(1980\)](#) stressed consumers’ preference for differentiated goods. The Krugman model highlight the role of scale economies as the basis for agglomeration incentives creating a “home market effect” in international trade.

A simultaneous contribution from [Ethier \(1982\)](#) studies the importance of international economies of scale based on the international division of labour. [Ethier \(1982\)](#) makes a compelling theoretical presentation of the rationale for trade in intermediate goods as a way to exploit economies of scale external to the firm at the international scale. Other contributions

from [Krugman \(1991\)](#) onwards explored the impact of geography and the likely formation of “core/periphery” patterns as a result of international trade. There are therefore compelling theoretical arguments to explain the different aspects of globalisation. International trade theory recognises that firms are the main drivers of trade patterns, as shown by the important number of studies based on the [Melitz \(2003\)](#) model explaining firm’s export decisions.

Evolutions in the scope and organisation of firms lead countries to question the national bounds of firms, the interests of which no longer coincide with those of their countries of origin. Similarly, the new wave of globalisation triggered a slow industrial re-composition along the new lines of comparative advantage between the old and new players of globalisation. It is increasingly obvious that MNC choose locations depending on broader dynamic comparative advantages, which now encompass concerns regarding taxation, institutional quality, labour regulation, etc. Some factors in industrialised countries are facing a sharp fall in demand as industries move to more competitive locations, creating structural unemployment in large segments of the labour force.

Globalisation means that countries (and regions within countries) will have to develop strategies to make the most of their international comparative advantages while at the same time providing employment opportunities for the other domestic factors not needed by the IDPP. This is an especially daunting challenge for countries whose comparative advantage mostly rest on natural capital. Finding a balance between sustainable use of natural capital, employment opportunities for the local population and international competitiveness is without grandiloquence the challenge of the first half of the century for many countries.

This is especially hard since current comparative advantage may have to be abandoned as countries undertake structural change. Although development can theoretically be pursued solely based on comparative advantage, economic dynamics usually involve a shift from basic, natural capital (or pollution) and labour intensive productions to more produced capital and innovative production. In this process, the average income of the population increases creating both the labour force and the demand for those products.

The equation of structural change is made more complex in a phase of globalisation as countries and regions cannot focus on the production of goods but merely on the production of segments of the global supply chain. Competition to attract the segment of the IDPP matching the characteristics of the country is fierce, since countries must now negotiate with the “footloose” MNC responsible for localisation decisions. To civilise this competition, the World Trade Organisation supervises multilateral agreements, sets global norms to prevent blatant cases of social or environmental dumping or unfair competition.

Another answer gaining momentum is based on the realisation that agglomeration forces and centre/periphery patterns are better managed in larger blocs. Following the European Union, regional trade blocs and agreements are currently negotiated, to open regions to trade while gaining power in international negotiations. Nonetheless, the world economy is still an imperfectly integrated economy, somewhere between a collection of islands in autarky and a completely open and integrated ensemble. We just saw this has consequences for countries and regions competing for the best possible insertion in the global supply chain. Intuitively, the least homogeneous a country is in terms of factor endowments, the more geographically concentrated production is within its borders, the greater the challenges from globalisation. This is unfortunately this setting that best describes the conditions for natural capital use in this globalised context.

II.3 International trade and sustainability: more than resource trade in globalisation

We presented *supra* the building blocks of sustainability. The rationale for this thesis is rooted in the growing concerns regarding particular instruments of wealth: renewable and non-renewable exhaustible resources. The broader environmental question is one of the critique addressed to capital theory that gave birth to the DHSS model and the neoclassical theory of environmental economics (see section I). Exhaustible resources constitute, as any factor of production, a potential source of comparative advantage. Energy resources (e.g. oil, gas, coal, uranium, etc.), enter in the production of virtually any good or service, and constitute the main factor in extractive (iron, zinc, copper) and in transformation industries (steel). As such, both the values and magnitudes of exhaustible resources embodied in international trade are significant:

- Natural resource rents account for more than 20% of GDP in 28 countries including Russia, Saudi Arabia Iran and Venezuela.
- From 1998 to 2008, international trade in natural resources grew over 600%, from US\$ 613 billion to US\$ 3.7 trillion ([World Trade Organisation 2010](#)).
- In 2008 natural resources accounted for 24% of global merchandise exports ([World Trade Organisation 2010](#)).
- The 2008 value of natural resources in international trade exceeded the GDP of all but 4 countries, and was equivalent to the combined GDP of the poorest 131 economies ([IMF 2008](#)).
- At the regional level, natural resources occupied 74% of total merchandise exports in the Middle East, 73% in Africa, 70% in the Commonwealth of Independent States, and nearly

half (47%) in South and Central America (World Trade Organisation 2010).

- For 21 countries, natural resources represent export shares in excess of 80%, and in 9 countries they contribute more than 50% of GDP (Ruta and Venables 2012).

Exhaustible resources are therefore an important component of international trade. They are also a critical object of study (although not the only one) for sustainability. Developed and developing countries have different attitudes towards natural capital. In developed countries, natural capital is a small share of comprehensive wealth and does not constitute a comparative advantage or a potential force of agglomeration. There are interesting exceptions to this rule, such as Canada and Australia. Even in those countries, natural capital accounts for less than 15% of comprehensive wealth. In developing countries, natural capital intensity is vastly heterogeneous. Some developing countries are moderately to very intensive in natural capital while others are virtually without any natural capital.

Both categories of developing countries are to undertake a form of structural change, facing the hurdles mentioned above. After the initially indiscriminate post-war development strategies²⁷, growing evidence of trade-related issues with development and structural change in the context of resource abundance were presented in the literature on the “Dutch Disease” (Corden and Neary 1982, Corden 1984). Those contributions suggested a terms-of-trade effect under which resource abundant countries could see the resources intensive sector of the economy expand and generate inflation in the economy, which would in turn destroy the competitiveness of the manufacturing sector.

As a result, instead of undertaking structural change, resources abundant countries may revert to or stay in a state of pre-industrial specialisation in labour and natural capital intensive manufactures. After this early trade-focused rationale for the lack of structural change, Sachs and Warner (1995) proposed empirical evidence of a “Resource Curse”. The resource “curse” symbolises a statistical negative relationship between the growth rate of GDP and natural resource abundance proxied by a relatively high ratio of resource intensive exports to GDP. The favoured explanation for the curse in the recent year seems to rest on institutional characteristics (Van Der Ploeg 2011). A useful guide to the impact of institutions on sustainability is provided by ? who offer to discriminate between extractive and inclusive institutions. The former tend to encourage unsustainable management of natural resources and rent capture by an elite. The later are identified by the authors as the requirement for a balanced and lasting development. All in all, exhaustible resources have an impact on three levels:

- They are used as inputs in several sectors and are therefore needed to develop some

27. See Yi-fu Lin (2012) for a presentation of the failure of import substitution strategies and the Washington consensus, and the potential reasons behind those setbacks.

industries.

- They are, as a result, a significant part of physical trade.
- In countries and regions where natural resources constitute the most valuable factor of production, their management determines sustainability and development strategies.

In the permanent state of competition of a globalised economy, countries have an obvious interest in natural resources. Resource-rich economies need to exploit them sustainably to finance structural change and risk a stalling development if they fail to do so. The global supply chain does not require those countries to undertake structural change as long as it does not hinder their ability to supply those natural resources. The impulse has to come from within, bearing in mind that trade forces may actually go against structural change and diversification as they encourage specialisation in line with the *current* comparative advantages. Resource-poor countries need to secure a steady supply of resources to keep the production of their part of the global supply chain going.

The troublesome reality of globalisation is therefore the *de facto* interdependence between countries, paired with ever increasing competition. A development strategy in the context of globalisation must accommodate the static nature of specialisation to form comparative advantages with the fundamentally dynamic nature of development. To provide useful guidance for both resource-rich and resource-poor, developed and developing countries, it is therefore necessary to produce a model of international interdependence in the context of structural change.

In this context, we will, for the rest of this thesis, strive to propose a comprehensive framework to understand the interaction of international trade dynamics with the requirements and objectives of sustainability. To this end, we will first provide a survey of both the theoretical and the empirical literature on sustainability in chapter 1. The Dasgupta-Heal-Solow-Stiglitz (DHSS) model is the natural starting point for this, as it combines capital theory with the neoclassical theory of value. It fulfils the requirements for a theory of sustainability.

We will next present the Adjusted Net Savings (ANS) and Comprehensive Wealth indicators of sustainability and review how they can be linked to the theoretical models of sustainability. We will then present the critical role of institutions in shaping sustainability and explore the conceptual tools we need to mobilise to develop a comprehensive model of sustainability. We discuss the notion of steady-state since it is used in both environmental and ecological economics with different understandings and a different purpose. We conclude this first chapter with a non-formalised presentation of a closed economy framework derived from the literature.

We argue that sustainability is in essence the need to consider five dimensions of the *means* to development: maintaining comprehensive wealth, allowing for constant value consumption over time, guaranteeing intra and intergenerational equity and controlling for real substitutability between instruments of wealth. We also argue that the best way, even in a closed economy, to take those five dimensions into account simultaneously is to develop institutions, allocation and conflict resolution mechanism according to the subsidiarity principle. The subsidiarity principle is especially important when legal rights are weakly enforced, since it reduces the possibility of power or resource grabbing.

In chapter 2 we review the three fields of the literature that need to be matched to propose an open economy sustainability theory²⁸: the trade and the environment literature, the open economy resource economics literature and the empirical sustainability literature. We show through the analysis of the literature that the complexity of open economy sustainability comes from the rationale for international trade. Sustainability rules and principles are not fitted for the grey area, especially in terms of rights and responsibility, between complete country autonomy and perfect global integration.

This makes the implementation of additional sustainability measures necessary since trade flows do not reflect actual contributions to (un)sustainability. The concept of “virtual sustainability” proposed in [Atkinson et al. \(2012\)](#) presents empirically the consequences of unsustainable management via international trade. We stress that the literature tends to approach sustainability issues either as a static international trade problem of resource content (based on classical static trade models) or as a dynamic resource management issue (based on dynamic resource models). We argue that the dynamic interactions between international resource prices and domestic incentives to specialise or diversify in the context of structural change make the case for dynamic models of trade and sustainability. Such models would allow us to study the determination of world prices by domestic capital management decisions and vice versa.

Chapter 3 is devoted to the presentation of the first attempt to build such a model. We combine sustainability rules with the neoclassical growth model from [Cuñat and Maffezzoli \(2004\)](#) to compare how countries characterised by asymmetric endowments undertake structural change in autarky and free trade. We propose several scenarios to account for potential biases in structural change (e.g. faster accumulation of a given factor). We also compare the case where the two trading partners accumulate the same instrument of wealth against the case where they focus on different instruments.

28. An anonymous referee, in a report on an earlier version of chapter 2 noted that the literature on trade and sustainability does not exist as such.

We first find that, when all factors are needed in the production process, countries are better-off under autarky than free trade. This feature comes from the fact that exploiting a country's potential comparative advantage requires the reallocation of resources (the creation of intermediary goods in our model) following the asymmetric distribution of endowments in the country. As a consequence, productivity is reduced by the extra allocation decisions. We also observe that countries are worse-off when asymmetry in endowments is high, so that consumption and total wealth are actually lower. What we actually observe is the rationale to undertake structural change.

As countries reduce asymmetry by investing in produced capital using labour and natural capital, they increase comprehensive wealth and steady-state consumption. A third interesting finding comes when the two countries are accumulating a different factor. Natural capital abundant countries are relatively better-off compared to produced capital abundant countries in autarky. This last finding suggests that autarky might be a better course for countries that are abundant in natural capital and would only accentuate this specialisation when opening up to free trade. We conclude with the observation that although both countries lose in free trade compared to autarky, trade liberalisation comes with gains from trade in the production sector in the course of structural change. Originally scarce factors see their price fall faster while originally abundant factors see their price increase more slowly. Those amendments to the price path modify incentives to invest in one instrument of wealth with respect to the others. As a consequence, we call for those gains from trade resulting from factor reallocation to be added to Adjusted Net Savings (ANS), saved for reinvestment and not consumed.

Chapters 2 and 3 provide a framework for the analysis of sustainability in the presence of international trade. We stress the role of increasing returns to scale and institutions in shaping trade and development patterns in the current phase of globalisation. In chapter 4 we use the [Ethier \(1982\)](#) model on the international division of labour to investigate the impact of increasing returns to scale on the requirement to save some of the gains from trade for sustainability. We conclude that based on the impact of increasing returns to scale on factor prices, the international division of the productive processes actually commends more savings as it creates an externality on the factor prices path.

This result suggests that natural resources abundant countries are critical to global sustainability, as the way they make natural resources available to the global supply chain will have an important cumulative impact on natural resources prices. We propose a reinvestigation of the resource curse, arguing that the Dutch disease and the extractive institutions that are the basis for the resource curse are actually two sides of the same coins. Extractive institutions create conditions for an increase in the size of the natural resource sector to extract more rents and

increase the size of the comparative advantage, while a trade-induced increase in the size of the natural resource intensive sector will create more appetite for rents and reinforce institutional extractiveness.

We propose to use the pattern of trade in natural resources intensive goods (in terms of one way, interindustry trade versus two ways, intraindustry trade) to define two possible paths for resource abundant countries. Structural change can either take the form of unsustainable depletion of natural resources before the build up of a produced-capital intensive productive base, or the composition of this productive base by sustainable reinvestment of natural resources rents. We argue that countries engaged in one way trade in natural resources intensive goods are likely to follow the first unsustainable path, so that the trade pattern in those goods can be used as a proxy indicator of un-sustainability.

In the final section of chapter 4 we turn to the impact of institutions on resource abundance and try to provide a better understanding of the dynamics behind the formation of the “institutional drift” as in ?. We propose to use the dislocation of the Soviet Union as a natural experiment in institutional sameness with observable heterogeneity in natural resources abundance. Using correlation in ranks, we make the hypothesis that although the Russian Federation can be considered to be part of natural resources abundant countries because of the share of natural resources rent in GDP, its reinvestment behaviour as estimated by Adjusted Net Savings (ANS) is actually closer to its relatively resources poor neighbours.

This observation suggests sustainability policy should be undertaken at a regional scale, as defined by co-evolution in ANS, since a country by country approach may fail because of regional interdependence in reinvestment policy. We conclude the section by stressing how counterfactual evaluations based on sustainability rules are critical to sustainability assessment. The cumulative nature of institutional and reinvestment paths makes the case for the creation of benchmark paths to situate a country’s current level of comprehensive wealth in the great number of possible paths. This is even more important when considering the inherent uncertainty in investment decisions.

We conclude from those results that international trade, in a world characterised by a process of globalisation and imperfect openness, has a profound impact on sustainability. We propose more comprehensive national sustainability assessments, coupled with regional assessments to control for interdependence. The empirical findings based on “virtual sustainability” and the results of our simulations concur to suggest that some gains from trade should go hand in hand with extra savings. The definition of regional sustainability blocks could legitimise the use of trade management instrument as a way to make those extra savings available to society as a whole.

CHAPTER 1

Sustainable development in economics: the emergence of sustainability

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Introduction

IN this first chapter, we review the development of the theory of sustainability. Based on the “building blocks” from the general introduction, sustainability can be defined as the analysis of the *means* for a sustainable development. Sustainability is based on capital theory, which provides conceptual tools to define values associated with the environment of human beings. Those values turn physical and immaterial components into instruments of wealth, which can be combined to satisfy needs and wants.

Those needs and wants are the sources of value as defined by the utilitarian theory of value. Utilitarianism forms the basis for the efficient allocation of resources in a geographical space. This allocation is understood as optimal under the Utilitarian ethic. The combination of capital theory with the Utilitarian theory of value is the basis for the weak sustainability paradigm. The weak sustainability paradigm emerged from the early DHSS model (Dasgupta and Heal 1974, Solow 1974, Stiglitz 1974) and the definition of the Hartwick rule for sustainable reinvestment (Hartwick 1977, Asheim et al. 2003).

Those theoretical contributions required empirical confirmation. A first assessment of the state of comprehensive wealth was made by Repetto et al. (1989). Soon, the “London school” of sustainability proposed the Genuine Savings (GS) or Adjusted Net Savings (ANS) as an indicator of sustainability (Pearce and Atkinson 1993, Hamilton 1994). After a period of relative rivalry between ANS and the Green Net National Product (GNNP), ANS are adopted as the best theoretically grounded indicator of sustainability (Dasgupta 2009). Still, the indicator fails to convince proponents of strong sustainability, who still believe that money-value sustainability is over-estimated because of market imperfection and physical limits.

To propose a definition of sustainable development and sustainability it is critical to take into account the contribution of institutions. Following Acemoglu and Robinson (2012) institutions can be defined as extractive when they favour the interest of a minority, and inclusive when they offer opportunity and voice to every agent. The presence of inclusive institutions is critical to sustainability: exclusive institutions prevent intragenerational equity. Exclusive institutions also limit intergenerational equity as they foster market inefficiencies and favour short-termism through prevalent rent-seeking behaviours. We discuss the central role of equilibrium analysis for sustainability, and stress how equilibrium analysis should only be undertaken if indicators of disequilibrium are also available.

We end the chapter with a proposition for an integrated sustainability framework. Sustainability is characterised by the realisation of five dimensions: maintaining comprehensive

wealth over time, maintaining constant consumption over time, controlling for money-value substitutability to be consistent with physical substitutability, guaranteeing intergenerational equity and fostering intragenerational equity. Working along those five dimensions will guarantee sustainability while helping to select consistent transition paths under uncertainty. Under this framework, time consistency at the most aggregated level is guaranteed using current value indicators while present value indicators are used to make adjustments to the development path as society moves in time and uncertainty is reduced. On this conceptual basis, we can propose a characterisation of the action of trade variables and mechanisms on sustainability.

In section I we present the construction of the weak sustainability paradigm, with the formation of the DHSS model (subsection I.1) and the elaboration of Adjusted Net Savings (subsection I.2). We then present the role of institutions in subsection II.1, discuss the concept of steady-state (subsection II.2) before presenting a framework for sustainability analysis (subsection II.3).

I The development of the weak sustainability paradigm

The neoclassical theory of value builds on capital theory. As in Fisher (1906), perfect substitutability between instruments of wealth through exchanges is therefore build-in. The neoclassical paradigm central claim is that market mechanism allows for an optimal allocation of resources (in the Pareto sense) under the constraints of all rival resources available. This claim was proven to be true under pure and perfect competition (Arrow and Debreu 1954). But this rigorous intellectual construct failed to address some documented stylised facts.

A first criticism on the ability of markets to provide a social optimum was formulated by Keynes (1936) who stressed the possibility of a permanent situation of under-employment. Keynes believed however that the right set of policy measures could bring down unemployment and reduce spare capacity. Keynes' critique could be deemed conjunctural¹ but another issue related to efficiency in use of instruments of wealth would soon emerge. Coase, in his totemic contribution *The problem of Social Cost* (Coase 1960) introduces the concept of externality. The notion of externality highlights the fact that some actions bear no cost (or generate no advantage) to the agent undertaking the action but do so for the agent at the receiving end. A perfect illustration is air or water pollution. As there is no price paid or benefit received, the externality can endure. Coase thought of the problem of externalities from a business perspective, but stressed more generally that markets could not be efficient because of property rights problems and information issues.² Both Keynes and Coase question the efficiency of market mechanisms under circumstances than can be regarded as exceptional. But externalities can be found everywhere, and especially in the emerging analysis of environmental issues. Coase's critic and the solution presented in the Coase theorem framed the way environmental issues would be dealt with in economics.

The environmental critique of the neoclassical paradigm stems from the notion of externalities with the seminal work of Ayres and Kneese (1969). Those authors stressed the importance of material flows to assess production processes, and discussed how to "internalise" externalities. The Club of Rome report (Meadows et al. 1972) then cast doubt on the lasting of the current stocks of materials. The final critique came from Paul Erlich's book, *The Population Time Bomb*. The last two brought back into the agenda the question of absolute scarcity. Erlich's work was a direct reference to the early observation of Malthus (1817) regarding diminishing return and population growth. The Club of Rome put more emphasis on the material intensity of production processes in societies entering mass consumption, following the conclusions in

1. And would be treated as such by the monetarists and M. Friedman.

2. G. Akerlof elaborates on this point with the theory of adverse selection in the context of asymmetric information.

Ayres and Kneese (1969). Recognition of the possibility of absolute scarcity would come as a threat to the relevance of allocation mechanisms (and the role of prices as a signal) based on relative scarcity. Those concerns were not new. Problems regarding pollution and environmental damage were acknowledged for some time. Hotelling (1931) proposed a rule of optimal depletion in the context of complete markets to answer the questions raised by the conservationist movement in the United States. But the rule holds in the context of efficient markets. Still, those early works aimed at amending the marginalist framework, when in the early 70's attention was directed to finding an alternative to it. This effort would later be articulated by ecological economists.

The final critique came from philosophers concerned with the social dimension of the “invisible hand” and market mechanisms. As numerous commentators and careful readers have since stressed, Smith understood the invisible hand as part of a social context, described in his *Theory of Moral Sentiments* (Smith 1759). But subsequent theoreticians in the neoclassical approach tend to overlook this social context.³ Setting aside the reminiscences from the Marxist superstructure, this argument was most eminently defended by John Rawls. *A Theory of Justice* (1971)⁴ triggered a controversy regarding the plausibility of the representation of society in neoclassical economics⁵ Rawls belongs to the philosophical school of the social contract (Rousseau 1762). After the emergence of the welfare state, Rawls proposed a model for a “fair” society centred on the social contract. Rawls (1971) explains that equity is the core of any social contract, and as such of any equitable and sustainable society. He develops the concept of justice as fairness, trying to propose an alternative to utilitarianism by reconciling equality and liberty.

Rawls proposed the concept of the “original position”. One should decide on his conception of justice behind a “veil of ignorance”, that is without knowing in advance his position in society. “no one knows his place in society, his class position or social status, nor does anyone know his fortune in the distribution of natural assets and abilities, his intelligence, strength, and the like. We shall even assume that the parties do not know their conceptions of the good or their special psychological propensities. The principles of justice are chosen behind a veil of ignorance.” (Rawls 1971). If the social conception of justice was established this way, Rawls concludes that everyone would favour the option were the worst-off individual in society is as well-off as possible, or a least not below the minimum one would in objectivity sets for oneself. There

3. This argument is back in full force in the context of the current (2007-) financial and economic crisis. It is common to hear commentators argue that the crisis is the consequence of market mechanisms eroding the social structures on which they rest.

4. We worked with the 1987 French edition which translation was supervised by Rawls himself. The edition is amended to take into account some of the reactions and critique to the original edition.

5. This is obviously not the sole impact of Rawls' work, but the most relevant one to the study of the formation of the sustainability paradigm we are conducting here.

should therefore be a minimum of intragenerational equity, were individuals who are better-off than the position they choose behind the veil of ignorance offer a “fair” compensation to the people that are worse-off. But one should also be concerned with intergenerational equity, as the fact that some generations are better-off than others would also be a breach of the “original position” argument. A theory aiming at producing the best possible social outcome should therefore be concerned with intergenerational and intragenerational equity if it is to be a theory of fairness.

Our aim in this chapter (and the next one) is to propose a conceptual framework for sustainability. To highlight the key concepts we use to do so, we will use boxes such as the box 1.1 below to highlight the milestones of the framework formation.

Box 1.1: Intergenerational and Intragenerational equity

Sustainability is first and foremost a normative choice, anchored in a theory of equity and justice. The need to preserve the fate of future generations emerges as human beings increase their ability to shape in the lifetime of a single generation the future of the planet and its ability to support life. But inter and intragenerational equity also have an instrumental value in shaping sustainability. Equity increases trust, confidence and stability in social choices and institutions, all of which makes a more efficient allocation of resources more likely.

I.1 The DHSS model and afferent controversies

The environmental and social critiques conflated to make the neoclassical model look out of touch on social and environmental imperatives. Potentially harmful market imperfections and absolute scarcity problems entered the economic agenda, even though those were beyond the scope of usual problems based of relative scarcity. All three criticism crystallised the issues that would be the core studies of sustainable development (see section II.2). The foundations of the theory of value, market mechanisms and the theory of capital as understood by neoclassical economists (usually on the Cambridge, MA side) were all under fierce criticism. Neoclassical economists addressed criticism in three steps, tackling problems in order of urgency. They reaffirmed that the theory of utility and capital theory combined are an efficient way to solve potential problems regarding the relation of human needs and wants and the environment providing the means. The newly constructed model build to back this claim makes extensive use of the new optimal control theory (see Bellman (1957), Chiang (1992) and Dorfman (1969)) to address issues regarding inter-temporal management of resources.

The first response was directed to Rawls. According to the maximin, what matters is not

the average or maximum level of well-being reachable in an economy, but the level of well-being for the worse-off individual. In a first contribution Arrow (1973b) proposes some objections to Rawls' principles. In a follow-up contribution (Arrow 1973a) he applies his interpretation of the maximin criterion to the problem of intergenerational equity. He mentions that Rawls warned him he did not intend the criterion to be used in this context, but Arrow does not see why the criterion would not be applicable.⁶ Arrow (1973a) shows that if the current generation is assumed to care for the future one, even at a discounted rate, then as long as the productivity gains in the current generation are higher than the discount rate applied to the later generation utility, the current generation will save. He generalises this result showing that if the horizon of the problem is extended to infinity, then the altruistic maximin criterion is equivalent to the utilitarian program of maximising the sum of discounted utility flows. The need to consider an infinite horizon is justified again in Dasgupta (2001) who argues against the possibility to set a limit for a shorter horizon. It seems indeed dubious that a rationale can be found to consider six generations and not seven or twenty-five.

Solow (1974) proposed to test the maximin criterion to integrate Rawls' idea in the neo-classical model with an exhaustible resource. He proposes an adapted program derived from the maximin (1.4). This is the program the social planner should maximise and not the usual level of utility. He notes that Rawls advocated the maximin for many problems, but not in the case of intergenerational equity. He endeavours to do so even if Rawls stated again in a note about taxation, that the maximin could not be used to determine the just rate of savings and held only within generations (Rawls 1974, p.142). It is interesting to note that the objective of maintaining consumption constant over time derives from Solow and Arrow's mathematical interpretation of Rawls's critique as the maximin, so that the social objective becomes $Min_t U(c(t))$ (Arrow 1973a, p.325). In the first Solow (1974) article, the production function takes the form:

$$Y = F(K_p, K_l, K_e) \quad (1.1)$$

Where Y is production, K_p is produced capital, K_l is labour and K_e is an exhaustible resource. The production function form retained is the Cobb-Douglas, as it is the simplest function form making all the entrants needed, so that if $K_e = 0, Y = 0$. If one assumes the following particular function:

$$Y = e^{mgt} K_p^g K_l^{1-g-h} K_e^h \quad (1.2)$$

6. The chronology of the articles commenting on Rawls's principle and the DHSS model is somewhat puzzling. In the 1973 article Arrow already refers to the forthcoming 1974 articles of Dasgupta and Solow, suggesting he had the opportunity to review them before publication.

With mg the rate of Hicks-neutral technical progress. Let C be consumption. Taking per capita values and controlling for technical progress, take $r = \frac{K_e}{K_l e^{mt}}$, $z = \frac{K_p}{K_l e^{mt}}$ and $c = \frac{C}{K_l}$. The income constraint is defined as $Y = \dot{Q} + C$ which yields the differential equation:

$$\dot{z} = z^{1-g-h} y^h - (n+m)z - ce^{-mt} \quad (1.3)$$

Where n is population growth. This yields an optimal path of given starting values $z(0)$ and $K(0)$. The problem of the management of a stock of finite resources under a maximin criterion is therefore “to find the largest constant c_0 for which there exist a function $y(t) \geq 0$ for all $t \geq 0$ ” (Solow 1974, p. 13) subject to:

$$K_l 0 \int_0^{\infty} y(t) e^{(m+n)t} dt \leq \bar{R} \quad (1.4)$$

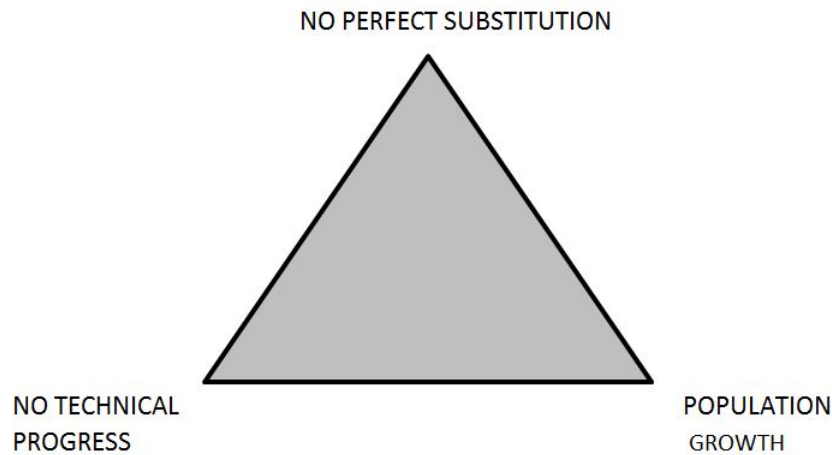
Using equation 1.4 with the differential equation yields the highest level of produced capital allowing for the largest constant consumption over time constrained by the finiteness of the exhaustible resource. Reformulating the problem as a more conventional minimisation problem and assuming the existence of a relative shadow price of produced capital in terms of the exhaustible resource then yields (with p the shadow price):

$$\frac{\dot{p}}{p} = -(1-g-h)z^{-g-h}y^h \quad (1.5)$$

Equation 1.5 states that the rate of change of the shadow price for the exhaustible resource stock should equal the sum of the rate of change of the shadow price for produced capital and the rate of return of the use of produced capital to reproduce produced capital. The representative agent is therefore indifferent between those two forms of capital. This rule of optimal depletion (use) for exhaustible resources bears an obvious resemblance to the Hotelling rule. Using the maximin criterion as a way to interrogate the neoclassical model on intergenerational equity, Solow finds ambivalent conclusions. His results depend on assumptions regarding the form of the production function, population growth and technical progress. The Cobb-Douglas functional form makes all the instruments of wealth indispensable in the production process, but it also builds in perfect substitutability between those at shadow prices.

The results of the Solow (1974) model can be summarised by considering three keys factors for sustainability. When considering resource allocation, one has to inquire about substitutability between instruments of wealth, the number of people sharing the use of those instruments and the possible improvements in the production of those instruments. Those factors can be organised as an impossible trinity (see figure 1.1) following Mundell, as it is possible to have two of those factors only by giving up on the last one. If one considers no technical progress,

Figure 1.1: The impossible trinity to maintain consumption constant



Source: Author from Solow (1974)

then one needs no population growth and perfect substitution. If one has population growth then one needs perfect substitutability and technical progress. If one has imperfect substitution then one needs technical progress and no population growth to ensure sustainability. Solow (1974) is only concerned with one angle. If there is no technical progress, capital must be accumulated fast enough (through perfect substitution of the exhaustible resource by produced capital) to drive the produced capital/labour ratio to infinity as the exhaustible resource/labour ratio goes to zero. Conversely if you have population growth, you need technical progress and perfect substitutability to maintain consumption constant, especially if population growth is geometric or more.

The exploration of the final case (the no substitutability between different instruments of wealth case) will be presented in section II. Solow (1974) is quite optimistic as he notes from studies of factor shares in production that produced capital already enters for much more than exhaustible resources in the production process (Solow 1974, p. 17). Works from Dasgupta and Heal (1974) and Stiglitz (1974) reach similar conclusions, setting more accurate conditions regarding the shape of the optimal path and the mathematical conditions surrounding the maintenance of constant consumption. The Dasgupta and Heal (1979) textbook summarises the findings. Those conclusions gave birth to the Dasgupta-Heal-Solow-Stiglitz (DHSS) model, still the workhorse neoclassical model for the treatment of exhaustible resources. It is worth stressing that in this model, the result of the production process (the monetary value of income) can be used both for consumption and investment. The DHSS model inaugurates this assumption in models with exhaustible resources and it is still used by default. It is not clear whether this assumption is made as a simplifying assumption or in an explicit reference to Fisher.

It is interesting to see how Solow used the maximin criterion to tackle intergenerational equity when Rawls never intended it to be used this way. There is a “fundamental disequilibrium” between generations. Indeed, future generations can inherit capital, institutions and other benefits from present ones, but the inverse is not true. Egalitarianist intergenerational equity ensures that the next generation inherits at least what the current generation inherited from the previous one. But it precludes any increase in the inheritance as then the next generation would be better-off than the current one. This would also be a breach of intergenerational equity. Intergenerational equity understood as intergenerational equality leads to the purest egalitarianism and the impossibility of progress. Solow (1974) also shows that the maximin criterion is highly dependent on the initial condition. “if the initial capital stock is very small, no more will be accumulated and the standard of living will be low forever” (Solow 1974, p.11). Therefore an application of the maximin in economics should be understood as:

- The objective of constant consumption over time as the condition for intergenerational equity.
- The underlying condition on the capital stock from which the flows of services (i.e consumption) were to be derived. Early generations can have a higher consumption/capital ratio, because what they need to pass is a proper technical progress adjusted capital to the next one.

The maximin was used as ethical basis for an implicit behavioural rule regarding consumption and savings (in fact investment) in economics. But this “social contract” between generations was sealed in an implicit way and is based on relatively strong assumption regarding substitutability, the course of technical progress and productivity gains. As for population growth, it is assumed to be exogenous, as in the Solow (1956) model. Therefore, just like Malthus, the DHSS model does not integrate a mechanism of endogenous growth. As Solow (1974) and the other founding articles of the DHSS model are concerned with finite resource management, they do not tackle the prime concern of Rawls’ work, intragenerational equity. Although the DHSS model would become the basis of the neoclassical treatment of sustainability, the question of intragenerational equity is, to our knowledge, never mentioned. It is usually argued that intragenerational equity is addressed with different tools and in different models which ambition it is to tackle this particular issue.

Rawls (1974) reminds us of the principle of democratic justice: “Each person has an equal right to the most extensive scheme of equal basic liberties for all” and “social and economic inequalities are to meet two conditions: they must be (a) to the greatest expected benefit of the least advantaged members of society (the maximin equity criterion) and (b) attached to offices and positions open to all under conditions of fair equality of opportunity” (Rawls 1974, p.142).

Any effort to provide guidance regarding the transmission of capital that claims to rest on a form of maximin should therefore be preoccupied with point (a). A transmission of capital from a better-off individual in the (theoretical) early generation should therefore be scrutinised to make sure this transmission will be to the benefit of the “least advantaged members of society”.

The DHSS model confirms the status quo in economics: market mechanisms take responsibility for capital accumulation and redistributive policies take responsibility for tackling inequalities. So economists continued to study inter and intragenerational equity separately. Intergenerational equity is the basis of capital accumulation and it is as such fully integrated in the economic analysis. Intragenerational equity is a second rank objective as far as economic efficiency is concerned. It should be dealt with using the relevant redistributive policy (depending on the preferences of voters) as “No reliable theory exists to integrate those to a comprehensive economic development approach” (Arrow et al. 2010).

This is in itself a major issue when using the DHSS model to build a theory of sustainability. Still, as in the Cambridge/Cambridge controversy, one is left with the impression that while Rawls’ objections were not completely addressed, the other side of the argument won by proposing a convenient, intuitive and formal approximation. Environmental economists seized the opportunity of a formal framework, compatible with tools such as the Hotelling rule to propose extensions on the theme of optimal resources management.

I.1.1 Sustainability from the DHSS model: The Hartwick rule

A first seminal contribution to the corpus of natural resources optimal management would soon come with John Hartwick (1977) and his article on *Intergenerational Equity and the Investing of Rents from Exhaustible Resources*. Using the Solow model as a background, Hartwick shows that under the assumption of zero population growth, investing all profits and rents from exhaustible resources into produced capital was the way to prevent “over-consumption” of resources by one generation and insure equity between generations. This result is crucial as it provided the first policy rule to manage exhaustible resources at the macroeconomic level. The “Hartwick rule” has been intensely debated since. A first generalisation is provided by Dixit et al. (1980). Solow (1986) links it to the welfare approach developed by Weitzman (1976) (see below). For a recent review of the multiple interpretations of the Hartwick rule see Asheim et al. (2003). Sato and Kim (2002) offer a comparison of the Hartwick rule against another rule based on conservation laws.

The Hartwick rule is critical to the emergence of weak sustainability as it gave the field a

clear and intuitive yardstick to assess sustainability. It also provided weak sustainability with an agenda. Sustainable reinvestment demands estimates of the current natural capital available since only “What gets measured, gets managed” (Heal 2011, p. 1). As such, the Harwick rule creates the need for environmental accounting (see section I.2). If natural resources can be integrated in an accounting framework, they can be optimally managed using shadow prices like any other asset. Dynamic optimisation can take place. Under the mathematical translation of the neoclassical theory of value, marginal costs and marginal utility are shadow prices, values that are the mathematical solutions of the optimisation problem and therefore the socially optimal ones as well. If markets are efficient, market prices are shadow prices and represent the prices maximising the allocation/depletion problem considered. A set of complete and efficient markets in a utilitarian society theoretically delivers the social optimum also for natural capital.

With a policy rule for optimal reinvestment and an agenda to develop natural capital accounts, the weak sustainability paradigm was only missing indicators to make sustainability issues explicit to economic agents. The most natural was to link the Hartwick rule to existing indicators, which were after all also sourced in optimal control theory. The first contribution to that tradition is doubtlessly the seminal article of Weitzman (1976) which provided a welfare interpretation of the Net National Product (NNP). This effort is to be understood in the context of the redefinition of the goals of development and the role of GDP growth. Weitzman (1976) shows that under relatively strict (heroic) assumptions, NNP is also an indicator of dynamic welfare. Therefore, as the DHSS model and the Hartwick rule are also grounded in welfare theory, natural capital management can be linked to the welfare interpretation of the NNP. Solow (1986) extends the Weitzman model in the context of an exhaustible resource, then Hartwick (1990) extends it again for pollution and renewable resources. Asheim (1994) investigates the potential impact of a non-constant rates of utility discounting. Weitzman (1997) provides another extension for technical progress and Asheim and Weitzman (2001) show that real NNP is an accurate indicator of dynamic welfare variations.

Starting with the Repetto et al. (1989) practice of accounting, empirical measures of wealth and instruments of wealth are proposed by Pearce and Atkinson (1993) and Hamilton (1994). As a consequence, the debate shifts from the importance of income derived from instruments of wealth to the importance of wealth itself. This shift is far from minor. Under mainstream welfare analysis, what matters is income from instruments as the final aim is to improve welfare. Optimal management of wealth instruments is only instrumental to this end. But the results of the “London school” (Victor 1991) on wealth accounting raises the profile of worries regarding substitutability. This leads the welfare school to pay more attention to wealth and investment in wealth. This shift is made easier by the simultaneous demonstration by Hamilton and Clemens (1999) and Dasgupta and Maler (2000) that dynamic welfare is also related to wealth

variations (from the capital theoretic perspective for the former and the welfare perspective for the later). With this, the welfare school gradually gives up on NNP and GDP, to adopt the capital theoretic perspective derived from the newly established “green national accounts” (Dasgupta 2009).

The reunion of the two traditions inside the weak sustainability paradigm allows for a better understanding of the links between optimality and sustainability. Contributions relying on optimal control theory focus on producing a path, stressing the optimal way to transition from current conditions to a Pareto-optimal steady-state. But a competitive and optimal path is not necessarily sustainable in the maximin or utilitarian sense. To achieve sustainability under optimality, the literature stresses the need to use shadow prices to evaluate assets. This debate is a natural extension of the debate on the Hartwick rule as the Hartwick rule is demonstrated to represent the rule for sustainability. A first contribution to this debate is [Asheim \(1994\)](#) who studies the conditions under which the Hartwick rule might lead to sustainability. He shows that “Hartwick’s rule characterises a sustainable development; it is not a prescriptive rule for sustainable development” ([Asheim 1994](#), p. 262). Hence, a sustainable economy follows the Hartwick rule but following the Hartwick rule does not guarantee sustainability.

[Arrow et al. \(2003\)](#) show that population should be included in any model of sustainability and discuss the conditions of this inclusion. If population is assumed to be exponential, then per capita sustainability should be assessed on an optimal path. If not, all the assets considered in the model should have at least a non negative rate of growth to ensure sustainability (and the relevance of population growth). [Buchholz et al. \(2005\)](#) demonstrate then that if a competitive path is equitable, it must satisfy the Hartwick rule. Following the Hartwick rule generates an optimal path and an optimal path necessarily follows the Hartwick rule. [?](#) then investigate the relationship between population growth and the savings rate. They show that in the DHSS model with an efficient path and constant savings rates, population growth has to be quasi-arithmetic for the path to be a maximin or classic utilitarian, ensuring sustainability. [D’Autume and Schubert \(2008\)](#) propose a DHSS model where the exhaustible resource has an amenity value. They notably show that under a CES function with a low elasticity of substitution, it is optimal to preserve a minimum level of natural capital to ensure sustainability. [Hamilton and Withagen \(2007\)](#) explore the links between the rate of change in utility and genuine investment with multiple instruments and externalities. [Cheviakov and Hartwick \(2009\)](#) finally extend the model of [?](#) including decay in produced capital and exogenous technical progress. Under this setting, there is a “race” between the rate of decay of produced capital and technical progress. Only a high enough rate of technical progress can maintain sustainable per capita consumption.⁷

7. The Marxist parentage of this last result is quite interesting.

Those contributions illustrate the diversity of the reinvestment rules depending on the model used and the assumption regarding technical change and population. [Hamilton and Hartwick \(2005\)](#) and [Hamilton and Withagen \(2007\)](#) both study the possibility of paths where consumption is unbounded and not kept constant over time. The later show how unbounded consumption may in the end lead to higher wealth. Of importance to a sustainability framework here is the notion of the development path. Sustainability is defined as a state, an ensemble of static desirable characteristics and as a path to transition from the current state to this sustainable state (see section II.2 for a discussion on the steady-state as an analytical tool). This begs interrogations on the possibility to run comparisons between periods and countries. [Asheim \(2007\)](#) tackles the first problem by pointing at the importance of having proper price indexes to evaluate capital and welfare at different points in time⁸. In a similar exercise for comparisons between countries ([Asheim 2010](#)) he stresses the necessity to use purchasing-power-parity measures to accommodate differences in the structures of economies, notably in terms of environmental amenities.

The Hartwick rule offered momentum to investigate the use of rules based on the analysis of development states and paths. The weak sustainability literature emerges at the end of the 1980's ([Pezzey and Toman 2002](#)) from attempts to better characterise the instruments of wealth needed along those paths and at those optimal states. The emphasis on sustainability and the maintenance of wealth according to the neoclassical theory of value and the principle of intergenerational equity gradually overtakes more conventional indicators such as the NNP. The new field merges methods from environmental economics, resource economics, capital theory, welfare theory and growth theory to produce prescriptive rules regarding the management of resources in the economy: natural capital to start with, but produced and human capital as well as the original DHSS model is developed and extended.

Box 1.2: Maintaining Wealth

The Hartwick rule stresses the need maintain the productive base of the economy, as income and consumption are derived from it. Consuming the income derived from an instrument of wealth is possible only if consuming this income does not preclude the capacity of the instrument to yield income in the subsequent periods (see the discussion on the concepts of income in the general introduction). When it is impossible to obtain income without depleting the instrument the Hartwick rule commands to use the income as outgo to a new instrument of wealth to avoid overall wealth losses. We derived from [Hicks \(1946\)](#) the need to dedicate the difference between gross and net income to the maintenance of the instruments of wealth. This intuition is comforted by the Hartwick rule. Maintaining overall wealth is a prerequisite for sustainability, whether the Hartwick rule is seen as prescriptive or just characterising sustainability.

8. Notably a Divisia index see [Asheim \(2006, p. 24\)](#) for a presentation of the original article by [Divisia \(1925\)](#).

I.1.2 The Treatment of time and uncertainty

The characterisation of states requires an evaluation of the states and paths. Evaluation of the path requires a model and current value indicators, while states can be assessed using current value and/or present value indicators (see section II.2). Present value indicators and dynamic modelling both require a way to account for the time passing. As we saw supra in the debate over Rawls' maximin criterion, the treatment of time is quite a topical issue. This is because time involves the comparison of instruments of wealth and individuals that are not available in the same market, making the determination of relative prices between those complicated and somewhat controversial. We covered the analysis of future income flows from capital units in Fisher (1906) and Hicks (1946) in the general introduction. Those are still the basis for today's research on those issues.

In Fisher (1906) the interest rate is the value return and is determined as the agents know with certainty future income flows. Income flows don't need to be constant but they need to be known. Uncertainty about future flows becomes a problem when dealing with intergenerational equity. If the present generation cannot estimate the value of the income flows it will pass on to the next generation, then it is impossible to assess equity. In DHSS-like models, this problem is solved by linking the pure rate of time preference to the utility function. The weight given to the future is represented by the rate of interest and/or the pure rate of time preference, depending on the model. If the pure rate of time preference is high (low), agents have a strong (weak) preference for the present and care less (more) about the costs and benefits occurring far away in the future.

Estimating a rate of time preference is not easy, but the implications are important. As suggested by Hicks (1946) The question of convergence is critical to the application of the neoclassical theory of value. One of the main critique coming from ecological economics (see section II.2) is precisely that convergence towards a steady-state is not guaranteed and probably more the exception than the rule. Still, most mainstream neoclassical economists accept this as at least a good enough approximation to understand the real world. Either as a concession to ecological economists or a tribute to the real world, authors have started to investigate the transitional dynamics, that is the evolution of the system between steady-states of toward the steady-state.

There are not many models of transitional dynamics applied to the study of sustainability, although it is certainly a promising lead. Eliasson and Turnovsky (2004) investigate such a model with a resource sector and labour allocation over time. They also investigate the consequences of several shocks and parameters values on the dynamics. Another example is

the article by [Cheviakov and Hartwick \(2009\)](#) mentioned above. An interesting lead is proposed by [Pemberton and Ulph \(2001\)](#) who show that what they term “inclusive income” is equal to the amount the economy can consume at one point in time while keeping the expected present value of utility for all generations constant. To do this, they add a new asset, “time”, associated with a shadow price that they treat as another capital stock. This technique will be used by [Pezzey \(2004\)](#) to capture the impact of international trade and exogenous changes in technology in a model to test the relevance of sustainability tests. It is also used in [Arrow et al. \(2010\)](#) (see section I.2).

The main bone of contention regarding the treatment of time is however centred on the discount rate. The discount rate is applied as a mean to calculate the present value of future income flows. It takes origin in the trade-off between two different instruments of wealth yielding income (the opportunity cost) and the preference for the present of agents. The discount rate was opposed by economists such as Frank [Ramsey \(1928\)](#) who judged the idea of discounting future flows akin to discounting future generations. He considered this “ethically indefensible”. Still the discount rate remains in favour, as it is now accepted that most agents effectively discount future flows whether they should or not. It is also convenient as a mathematical tool for facilitating convergence towards the steady-state.⁹ Discount rates have a major influence on the outcome of any inter-temporal valuation and come regularly under fire as the controversy over the [Stern \(2006\)](#) review illustrates. A high discount rate was used in the report resulting of relatively low impact of climate change in the long run. [Li and Löfgren \(2000\)](#) investigate the impact of the variations in time preferences for consumption and resources amenities.

[Gollier \(2010a\)](#) discussed the role of expectations and uncertainty in the Ramsey rule (which is used to determine the discount rate applied to future consumption flows in wealth calculations, see section I.2). Different rates can be estimated depending on the level of certainty and the time horizon. [Ayong Le Kama and Schubert \(2007\)](#) discuss the consequences of introducing an endogenous discount rate, growing with environmental quality. [Gollier \(2010b\)](#) studies discounting when there are concerns regarding biodiversity. He shows that changes in biodiversity should be discounted less than changes in consumption under certainty in the Cobb-Douglas case. [Traeger \(2011\)](#) shows how imperfect substitutability affects discount rates.

The literature on discounting is obviously voluminous and the articles mentioned here are merely examples. Decisions regarding discounting crystallise many underlying assumptions. An interesting contribution from [Ayong Le Kama and Schubert \(2004\)](#) investigates the possibility

9. [Ramsey \(1928\)](#) who didn't use a discount rate assumed instead there was an upper-bound to the level of “felicity” attainable by individuals. An interesting idea based on the assumption that the marginal utility of consumption is zero above the bound. [Ayong Le Kama \(2001\)](#) shows how, following the same philosophy, convergence towards the green golden rule path can be obtained.

that future generations may have different environmental preferences. They stress how beyond the formation of preferences, many path dependent factors will impact future environmental quality. As expressed for example in [Neumayer \(2000\)](#), discounting is related to the actual level of substitutability between the instruments of wealth. A high discount rate is much less of a risk for intergenerational equity if the substitutability of natural capital is high than when it is low.

This concludes our presentation of the DHSS model. The weak sustainability paradigm is organised as the merger in the contemporary versions of the DHSS model of the “welfare school” and the “London school” of sustainability. The latter brought another significant contribution to the paradigm, producing a present value indicator of sustainability: the Adjusted Net Savings (ANS). Using ANS sustainability can be assessed in conjunction with path assessments using the Hartwick rule and states assessments using present value indicators.

Box 1.3: Constant consumption over time

The imperative to maintain consumption constant over time comes from the Ordinalist transcription ([Arrow 1973a](#)) of Rawls' principle of justice in the DHSS model ([Solow 1974](#)). Maintaining consumption constant over time is the only ethically defensible position in terms of intergenerational equity, as it allows for both constant well-being and capital accumulation. Recent contributions from [Hamilton and Hartwick \(2005\)](#) and [Hamilton and Withagen \(2007\)](#) explore the possibility of unbounded consumption path which are compatible with sustainability. We will keep constant consumption over time as our goal in line [Arrow et al. \(2003\)](#) to take into account the possibility of a growing population.

I.2 Quantifying sustainability

The elaboration of the DHSS model of sustainability started in the early 1970's and although the basic framework was set by the end of the decade, it has been improved incrementally ever since. In the meantime, techniques were developed in environmental economics to estimate shadow prices in the absence of markets. Contingent valuation is the most commonly used method. It is based on willingness to pay (WTP), willingness to accept compensation (WTAC) and surveys of users of ecosystem services. Those sets of prices allowed for estimates of non-market components that were, according to the theory, part of Comprehensive Wealth. The development of contingent valuation is to be understood in the context of the broader use of market mechanism to solve environmental problems understood as externalities, as alternatives such as taxes face problems of social acceptability. Contingent valuation is valuable in itself, as a way to increase understanding of local human/environment interactions. Hence, this expensive technique is in most cases used to shed light on policy issues. The works on indicators

of sustainable development started when policy makers requested indicators to help better understand the impact of development and/or more local policies on sustainability. Reciprocally, after the first Rio summit in 1992, quantitative data was needed to bring flesh to Agenda 21 and other sustainable development initiatives. In the same vein, contingent valuation was included in the greater effort to produce Cost-Benefit Analysis (CBA) for policy makers on environmental issues. Those initiatives stress a point which became increasingly clear for ecologists and economists alike: costs outside of any accounting framework do not exist.

After the Brundtland report ([World Commission on Environment and Development 1987](#)), a first study by [Repetto et al. \(1989\)](#) tried to estimate the impact of resource depletion on national accounts. This was the starting point of a general push to expand national accounts to better value environmental assets. Those efforts will lead to the creation of the System of Environmental Economic Accounting (SEEA) developed and maintained by the United Nations. A presentation of the latest version can be found in [Dietz and Neumayer \(2007\)](#). In this presentation of the empirical estimates of sustainability the terms “income”, “investment” and “savings” are to be understood as referring to the accounting concepts, unless otherwise specified. One of the consequences of the Brundtland report was the development of capital-based measures of sustainability. Members of the “school of London” ([Victor 1991](#)) proposed what would become the Adjusted Net Savings (ANS) ([Pearce and Atkinson 1993](#)). This is the fruit of an effort coordinated by the late David Pearce ([Pearce and Atkinson 1992](#), [Turner and Pearce 1992](#)) to produce an empirical indicator able to determine if a country was on a sustainable development path. The first version of the indicator was termed genuine savings, which is still used today by many researchers, but for the clarity of exposition we shall use ANS only to designate the indicator. The authors writing on the DHSS model who favoured the Green NNP found common ground with the ANS, notably through further investigation of the Hartwick rule (see section I.1).

I.2.1 Presentation of the two approaches and the contemporary models of Wealth and Savings

In their first presentation of ANS, [Pearce and Atkinson \(1993\)](#) made a clear reference to the use of capital theory as a way to measure sustainability. The authors convincingly pushed for the development of natural capital measurement, as even imperfect accounting on the economic weight of environmental assets would be the best possible first step towards a comprehensive “economic-ecological” model. ANS are built from the start on the assumption of substitutability between natural capital and other forms of capital ([Pearce and Atkinson 1993](#), p. 104). The idea of ANS is to build on the Hartwick rule and the formalisation of [Solow \(1986\)](#) to calculate

an aggregate rate of savings on all the instruments of wealth. This savings rate will represent the evolution of wealth between two periods for a given economy. Following the DHSS model, this rate will be an indicator of sustainability. In this first article, the empirical test is simple. If Z is a given sustainability index then $Z > 0$ if and only if:

$$\left(\frac{S}{Y}\right) > \left[\left(\frac{\delta_M}{Y}\right) + \left(\frac{\delta_N}{Y}\right)\right] \quad (1.6)$$

Where S is Gross Savings, Y is income, δ_M is the depreciation of man-made(produced) capital and δ_N is the depreciation (depletion) of natural capital. ANS make explicit use of monetary values for natural capital, in the line of capital theory and the DHSS model. From inequality 1.6:

$$Z_t = \left(\frac{S}{Y}\right) - \left(\frac{\delta_M}{Y}\right) - \left(\frac{\delta_N}{Y}\right) \quad (1.7)$$

Where Z_t is ANS in t . In this first version of the indicator, [Pearce and Atkinson \(1993\)](#) claim that countries with positive ANS are sustainable and countries with negative ANS are unsustainable. From this original claim, only the later will survive the subsequent development and investigation of the properties of ANS. ANS is in fact a one-sided test: A negative rates of savings indicates un-sustainability, but a positive value does not guarantee sustainability.

[Hamilton et al. \(1997, 1998\)](#), [Atkinson and Hamilton \(2007\)](#) have reviewed the evolutions of ANS at different points in time. Subsequent study have since improved the measure. [Hamilton \(1994\)](#) investigates whether GNNP or ANS are the best indicator of sustainability from a welfare point of view, and concludes that ANS should be preferred. [Hamilton \(1996\)](#) discussed the role of defensive expenditure and the incorporation of pollution and pollution abatement. In an important article, [Hamilton and Clemens \(1999\)](#) present new ANS estimates and following [Hartwick \(1990\)](#) present ANS as the product of an inter-temporal optimisation problem. This problem yields a current value Hamiltonian:

$$H = U + \gamma_K \dot{K} + \gamma_X \dot{X} + \gamma_S \dot{S} + \gamma_N \dot{N} \quad (1.8)$$

where U is the utility function (utility depends on both consumption and pollution), K is produced capital, X is the stock of pollution, S an exhaustible resource stock and N the human capital stock. The γ s are the shadow prices. Dots indicate time varying variables. Adding international trade and capital depreciation, the measure of NNP is given by:

$$NNP = C + \dot{K} - \delta K + E - M + iA - (1 - be_F)F_r(R - g) - b(e - d) + \frac{q}{q'} \quad (1.9)$$

With C consumption, E exports, M imports, iA interests on foreign assets, R resources depletion, g renewable resources growth, d the dissipation of pollution, e the abatement of pollution, q the function of human capital accumulation, δ the produced capital depreciation, F_r is the resource rental rate, b the marginal cost of pollution abatement and be_F is the effective tax rate on production set by emission taxes. It should also be noted that under the assumptions of the model, human capital investment brings endogenous technical progress. Finally, the formula to calculate ANS from data is given by:

$$G = GNP - C - \delta K - n(R - g) - \sigma(e - d) + m \quad (1.10)$$

ANS are equal to Gross Savings (Gross domestic product minus consumption) minus the depreciation of produced capital, minus the net resource rental rate times the variation of the stock of exhaustible resources, minus the marginal cost of social pollution times accumulation minus dissipation of pollution plus investment in human capital.

This method have been used ever since by the World Bank to propose estimates of ANS. In a series of reports ([World Bank 1997](#), [2006](#), [2011](#)) the World Bank presented ANS estimates, discussed empirical challenges and potential applications. Besides yearly estimates of ANS using accounting data, the World Bank provides an estimate of comprehensive wealth. The method is best explained in [World Bank \(2011, p. 94\)](#). Wealth is defined as:

$$W_t = \int_t^{\infty} C(s)^{-r(s-t)} ds \quad (1.11)$$

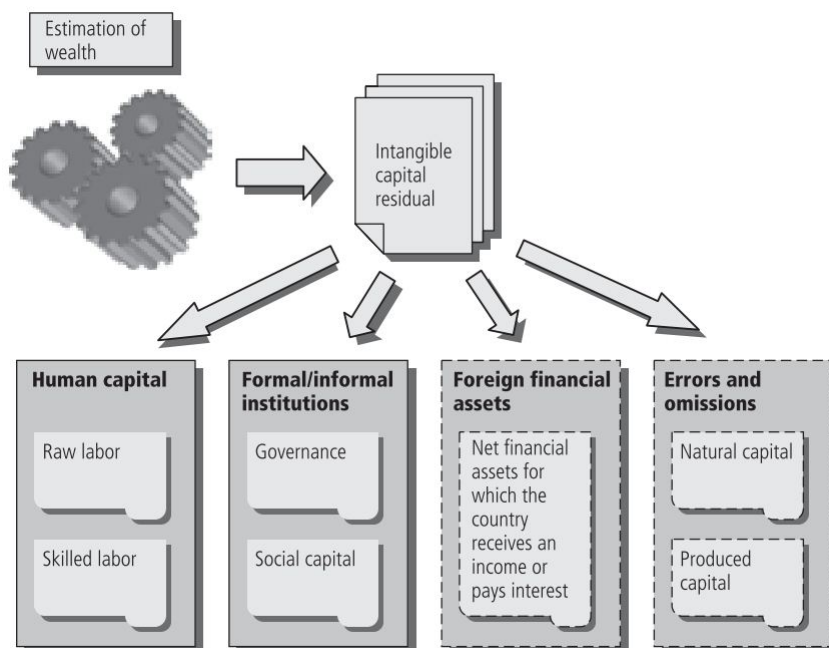
Where C is consumption, s in the current period and r is the social rate of return. r is calculated using the Keynes-Ramsey formula:

$$r = \rho + \nu \frac{\dot{C}}{C} \quad (1.12)$$

Where ρ is the pure rate of time preference and ν is the elasticity of utility with respect to consumption. The final term is the rate of growth for consumption, assumed to be constant. This value of wealth is obtained by assuming that the original observed level of consumption is sustainable. This value of wealth gives an upper bound to the estimate of wealth for a given country. The next step is to estimate the relative size of the instruments of wealth. Indeed, the very rationale for looking for an upper bound for wealth is precisely that some instruments of wealth can not be estimated in their entirety, or completely ignored. This claim is backed by the very high implicit rate of return on wealth if wealth was only composed of produced capital.¹⁰

10. In the example of Canada presented in [World Bank \(2011, p. 94\)](#) the implicit rate of return on produced

Figure 1.2: A proposed decomposition for intangible capital



Source: World Bank (2006)

The authors decompose wealth into three instruments: produced capital, natural capital and intangible capital. Produced capital is estimated using the Perpetual Inventory Method (PMI). Natural capital is estimated using value for urban land, energy and mineral resources, timber and non timber resources, crop land, pasture land and protected areas. Intangible capital is estimated as the residual of wealth once the two previous instruments have been subtracted.¹¹ An attempt to estimate the subcomponents of intangible capital can be found in the previous report (World Bank 2006, chap. 7, p.87). This disentanglement is critical as intangible capital appears to be the main source of wealth for every country where wealth estimates are available (see figure 1.2). By means of econometric estimates, the authors show that the biggest component of intangible capital is likely to be institutions, followed by human capital (see section II).

From the underlying theory of the DHSS model and the Asheim/Wietzman amendments regarding sustainability and optimality, the World Bank provides estimates using what we would describe as a “Top-Down” method: first estimate comprehensive wealth and then estimate the sub-components. This estimation method derives logically from data limitations and the rate of return puzzle. But another method is proposed in Arrow et al. (2010), method we would describe as “Bottom-Up”. It expands a previous article centred on the US and China (Arrow

capital is 35.9%.

11. See World Bank (2011, p.141) for more details.

et al. 2007). Using a starting point similar to Hamilton and Clemens (1999) the authors define sustainability as $\frac{dV}{dt} \geq 0$, with:

$$V(t) = \int_t^{\infty} [U(\underline{C}(s))e^{-\delta(s-t)}] ds, \delta \geq 0 \quad (1.13)$$

Loosely speaking, sustainability is characterised by the non declining present value of discounted utility flows at any point in time. Arrow et al. (2010) do not present an explicit model but they assume that V will depend on the current stock of assets and on expectations regarding the evolution of that pool of assets. They treat institutions as exogenous, as they claim no theory of political economy is available to “track the co-evolution of economic development and the economy’s institutions” (Arrow et al. 2010, p. 6). As with the first method, there is therefore no explicit concern for intragenerational equity. They then define shadow prices in a somewhat similar fashion to Hamilton and Clemens (1999), with the notable difference that they make felicity (utility flow) as the *numéraire* of the economy. Shadow prices are defined as:

$$q_i(t) = \frac{\partial U(\underline{C}(t))}{\partial C_j(t)} \quad (1.14)$$

The shadow price of consumption of good j in time t is the partial derivative of the utility of total consumption in t with respect to the consumption of good j in t . As for the shadow price of capital goods they are characterised by the two equations:

$$\frac{dV(t)}{dt} = \frac{\partial V}{\partial t} + \sum_i \left[\left(\frac{\partial V(t)}{\partial K_i(t)} \right) \left(\frac{dK_i(t)}{dt} \right) \right] \geq 0 \quad (1.15)$$

$$p_i(t) \equiv \frac{\partial V(t)}{\partial K_i(t)} \quad (1.16)$$

Where $p_i(t)$ is the spot shadow price of the i^{th} asset in t . Arrow et al. (2010) then makes explicit use of the trick proposed by Pemberton and Ulph (2001). They regroup all the exogenous variables (institutions included) into another asset which represents the value of the time passing:

$$r(t) = \frac{\partial V}{\partial t} \quad (1.17)$$

With $r(t)$ the shadow price of time. It is now possible to define comprehensive wealth as the value of all capital assets at shadow prices:

$$W(t) = r(t)t + \sum p_i(t)K_i(t) \quad (1.18)$$

From this fully optimised framework it naturally flows that the evolution of intergenerational

well-being is perfectly correlated with the variation of comprehensive wealth. Therefore “comprehensive investment” in “comprehensive wealth” is:

$$\delta V(t) = r(t)\delta t + \sum p_i(t)I_i(t)\delta t \quad (1.19)$$

This comprehensive investment is in fact a theoretically rigorous formulation for adjusted net savings. [Arrow et al. \(2010\)](#) then expand the scope of wealth to include explicitly population growth (stressing that what matters is per-capita comprehensive wealth), health capital, transnational externalities and total factor productivity growth.

The main difference between the “bottom-up” and the “top-down” method is therefore the way wealth is calculated. A first remark is that the second method is more encompassing, explicitly grounded in welfare theory (with the still controversial use of the statistical value of a life) and very data intensive. The first method is a priori less theoretically ambitious but provide a clear and detailed empirical background that is used to collect and build the dataset of the World Bank, used in the empirical test of the second methods. It seems that the two methods are more complementary than anything else. The World Bank’s method provide an upper-bond for wealth estimates, likely to overshoot especially if current levels of consumptions are not sustainable. The [Arrow et al. \(2010\)](#) method aggregates all available data and is likely to undershoot as the components of “intangible capital” are hard to estimate. It is interesting to note that the World Bank put an emphasis on the savings perspective by calling its measure Adjusted Net Savings, whereas [Arrow et al. \(2010\)](#) termed their equivalent “comprehensive investment”. As discussed in the introduction, in the long run in the neoclassical approach $I = S$ and both concept should yield an equal amount. But the [Arrow et al. \(2010\)](#) study should be given credit for being closer to the original Fisherian idea of outgo.

1.2.2 Development and discussion of ANS

Adjusted Net Savings (ANS) started as an empirical indicator of sustainability and was subsequently given theoretical foundations in [Hamilton and Clemens \(1999\)](#). But the original aim of [Pearce and Atkinson \(1993\)](#) was to provide policy makers with an indicator to assess policy regarding sustainability. The fall of natural resources price in the 1980’s (culminating in the counter oil shock of 1986) seemed to contradict the alarmed predictions of the Club of Rome report ([Meadows et al. 1972](#)). After a modest fall between 1958 and 1980, natural resources prices fell sharply (see figure 1.3) and stayed relatively cheap until the end of the century ([Maizels 1992](#)). This seemed to prove the Club of Rome wrong and cost Paul Erlich

Figure 1.3: Trends in commodities terms of trade 1958-1988

	Indices (1958–60 = 100)			
	1958–60	1968–70	1978–80	1986–8
<i>Non-oil commodities</i>				
UNCTAD index ^{b,f}	100	93	92	62
World Bank index ^{c,f}	100	97	90	58
IMF index ^{d,g}	100	95	91	61
<i>Petroleum^e</i>	100	70	390	211

^a Annual averages.

^b 39 commodities.

^c 33 commodities.

^d 34 commodities.

^e Average OPEC price (World Bank index).

^f Weighted by value of exports from developing countries in 1979–81.

^g Weighted by value of world exports in 1980.

Source: UNCTAD Monthly Commodity Price Bulletin (various issues) in Maizels (1992)

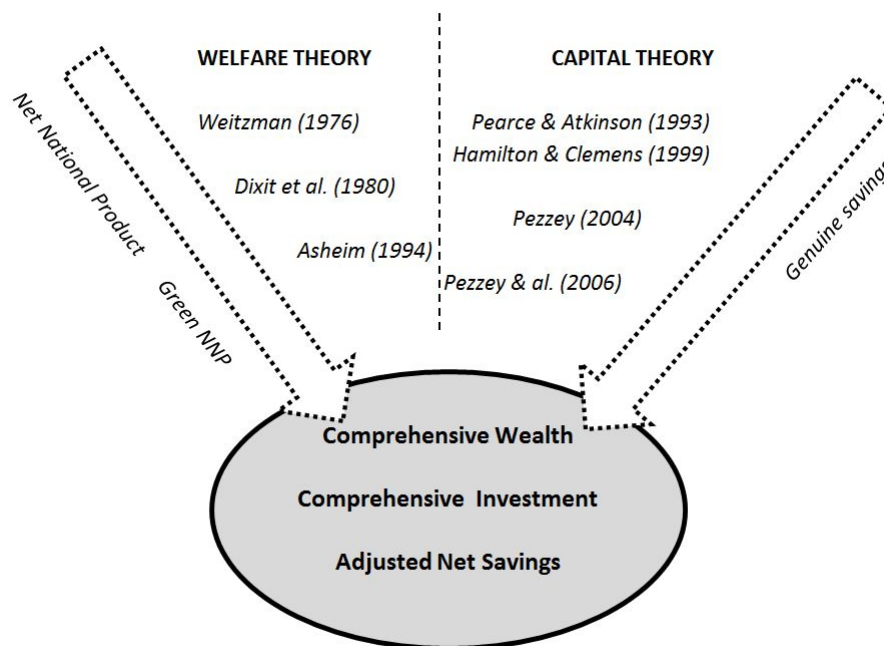
some money.¹² Still, Repetto et al. (1989) proposed convincing evidence that natural resources were still wasted.

Adjusted Net Savings can be seen as an original attempt to reconcile physical estimates of natural resources scarcity (how many tons of x left into the ground) with value-based estimates via the integration of those resources into an economic system. We explored in section I.1 the convergence of the “welfare school” and the “London school” over Adjusted Net Savings (see figure 1.4). The authors on the welfare side are behind the intellectual foundation of the “bottom-up” method. But a symmetric move was made by authors starting from capital theory and accounting, using the conclusions drawn from welfare theory to ground ANS more firmly in economic theory. This cross fertilisation would lead to an overall improvement in both the measure of ANS and the interpretation and reach of the indicator.

Pezzey (2004) proposes a theoretical foundation for ANS in situations not assessed in the original Hamilton and Clemens (1999) article: amenities, population growth, international trade and technical changes. Pezzey (2004) notably uses time as a productive stock following Pemberton and Ulph (2001). Dasgupta (2009) pushes further the case for ANS and comprehensive wealth estimates showing they are both a good policy evaluation tool and an indicator of sustainability. Hamilton and Bolt (2004) and Hamilton (2009) further investigate the links

12. The “Simon and Erlich” bet between Paul Erlich and Julian Simon is quite famous in the scientific community. Simon bet Erlich that the price of natural resources would fall during the 1980’s as proxied by a basket of five commodities: copper, chromium, nickel tin and tungsten. In 1990 Erlich send Simon a 576.07 USD check by mail.

Figure 1.4: Intellectual convergence towards Adjusted Net Savings



Source: Author

between theory and empirics, showing how to properly measure changes in the measured stock of natural capital, especially under exogenous world prices.¹³ Adjusted Net Savings estimates are provided by the World Bank, but some regional estimates have been computed by Pezzey et al. (2006) for Scotland and Ferreira and Moro (2011) for Ireland. The former find Scotland to be on a sustainable course and the latter produce estimates that are consistently smaller than the World Bank but include a broader range of assets. Atkinson and Hamilton (2003) link the resource curse to sustainability and ANS, offering further evidence that the resource curse is a mix of institutional problems and resource management issues.

The indicator gained ground as a predictor of sustainability and is increasingly used in academic studies. Bobilev (2005) uses ANS to back the need for environmental friendly fiscal reforms in Russia. Shmelev and Rodríguez-Labajos (2009) and Shmelev (2011) use ANS to build a multidimensional indicator of sustainable development. Heal (2011) proposes a review of sustainable development based on ANS. The United Nations now fully support comprehensive wealth as a critical tool to assess development prospects (Atkinson et al. 2012). Finally, the extension of green accounting led to the creation of a **natural capital committee** in the United Kingdom, followed by the first **World Natural Capital Forum** in Edinburgh in 2013.

ANS also provide a clear framework to assess traditional questions in resource and envi-

13. See chapter 2 section II for further discussion on exogenous world prices.

ronmental economics. Van der Ploeg (2010) explores the rationality of postponing savings and investments of rents from natural resources in resource-rich countries. Van Der Ploeg (2011) stresses the role of ANS in determining whether or country falls prey to the resource curse or not. But the emblematic use of ANS as a policy indicator is provided by Hamilton et al. (2006) who conduct a counterfactual exercise, estimating the counterfactual comprehensive wealth of resource rich countries had those followed the Hartwick rule. The exercise is presented again in World Bank (2006). ANS are a current value indicator, so that information about the future is theoretically incorporated into it. This information covers the transition from the present state to the steady-state (notably regarding consumption) and information about the steady-state itself. Still, as stressed in Hamilton and Withagen (2007) there can be multiple path to the same steady-state, or even a multiplicity of conditional steady-states. The use of counterfactual scenarios based on several sustainability rules makes the comparison of several sustainability scenarios possible (see chapter 4 section III).

Beyond the question of current sustainability, authors have also tested the ability of ANS to predict future level of consumption: negative ANS should indeed reduce future consumption as the productive base of the considered country is shrinking. Ferreira and Vincent (2005) observe that ANS tend to perform relatively better as a predictor of sustainability for developing countries than developed ones. They conclude this is related to the inaccuracy of human capital measurement which is critical to understand the sustainability of developed countries. Ferreira et al. (2008) investigate the impact of population growth on the reliability of ANS as a predictor of future consumption. Beyond the potential problems associated with data and amenities, technical progress and population, one of the potential shortcomings of ANS are on the demand side. ANS are a traditional supply side indicator from a macroeconomic perspective, in the sense that the welfare theory it is related too assumes the standard neoclassical dispositions regarding the price adjustment of demand. But it goes even further with ANS as the top-down method is explicitly build not only on this but also on the assumption that current levels of consumption are sustainable (see World Bank (2011, p. 142)). Arrow et al. (2004) identify theoretical reasons under which consumption could be above the level compatible with intergenerational equity in a DHSS model.

ANS are now firmly established as a current value indicator of sustainability. The indicator, although still criticised, is the most consensual inside the weak sustainability paradigm. As for the neoclassical theory, the weak sustainability paradigm is made attractive by its internal consistency and ability to provide an allocation rationale for *all* the instruments of wealth. ANS, eventually completed by counterfactual studies and present value indicators (see section II.2) can theoretically characterise a development path and allow comparisons between times and places. Stiglitz et al. (2009) advocated its use instead of GDP in their report on the

measurement of social progress. Nevertheless, sustainability is not sustainable development. Some important elements, such as institutions, are relevant to sustainable development and the definition of the ends (the social aims of development). They also happen to have instrumental importance for sustainability, as institutions condition to a large extent the efficiency of resources allocation mechanisms. In the second part of this chapter we present this instrumental value before discussing the concept of steady-state. We conclude with the first presentation of our framework for sustainability and sustainable development.

II Institutions, the Steady State and uncertainty: sustainable development in closed economy

Institutions are the key to resources allocation as they define and regulate interactions and conflict resolution between agents and/or social groups. A schematic characterisation can yield important insights into their impact on sustainability. Institutional evolution is better understood using the scale of a development path, stretching over several generations. Taking into account institutional dynamics requires a good assessment of the tools relevant for this kind of time frame, most notably the use of equilibrium analysis and the steady-state. Taking into account institutional dynamics allows us to propose a framework for sustainable development based on sustainability. We notably insist on the importance of the geographical scale and separate the analysis of the means from the analysis of the ends of development.

II.1 Policy and Institutions

It is useful to first define institutions. The most widely used definition is proposed by Douglas North in his 1991 article in the *Journal of Economic Perspectives*. Institutions are “humanly devised constraints that structure political, economic and social interaction. They consist of both informal constraints (sanctions, taboos, customs, traditions and codes of conduct) and formal rules (constitutions, laws, property rights).” (North 1991). It comes naturally from this definition that market mechanisms can be analysed as another social institution. Following those early works there has been a growing body of literature trying to analyse the role of a set of institutions (beyond market mechanisms) in the success or failure of economies. Institutional factors are especially solicited when explanations from mainstream economic theory seem to fail. This is also true for the analysis of the environment and sustainability.

Environmental and sustainability issues as they extend over a time frame far beyond the

horizon of a single individual, can only be solved by commitment over several generations. Institutions (formal and informal) are supposed to maintain this credible commitment. Ostrom (1990) stresses the fundamental role of those institutions for governing the commons. Institutions both formal and informal are critical to understand policy design and policy enforcement. Once a given policy is enacted (usually by an institution) it is enforced through another institution (the law, or market mechanisms). As an example, the failure to follow the Hartwick rule, which should be theoretical enshrined in sustainable reinvestment policy, is usually blamed on institutional weaknesses in (mostly developing) resource rich countries Hamilton and Atkinson (2006). The resource curse (Atkinson and Hamilton 2003, Van Der Ploeg 2011) is another example.

Institutions are complicated to consider from a sustainability perspective as they are shaped by both the ends of development and the appraisal of the means. The role of the ends in institutional formation is illustrated by the diversity of formal and informal institutions on the planet, largely responsible for the diversity of the human experience. Ends, as presented for example in the universal declaration of human rights from 1948 define social values and inspire rights (or liberties) and responsibilities. Dasgupta (2001) distinguishes between civil, political and socio-economic rights. In all those observable categories, societies may choose a quality associated with the considered rights. The ends can then be observed either as presence or absence of a considered right or responsibility, or by a qualitative difference in the extent to which it is observed in society. Again, those rights and responsibility can be enforced via a formal definition of rights in a legal system, or more informal institutions like customs.

We argue that the definition of the ends should be left to societies and defined by a political process. This societal discussion of the aims, the balance between several dimensions of life, is the essence of social or individual development. What we have to consider now is the share of the institutional setting that is instrumental to the rest of the development ends, namely the institutions that have an impact on the means of development. This is by the joint (but separated) consideration of ends and means, development and sustainability, that sustainable development can be achieved.

A good example of the definition of an instrumental value is the debate over substitutability. Real, physical substitutability is defined by physical characteristics that are in most cases observable in physical dimensions. Turning coal into energy requires a combination of physical forces resulting in an alteration of the form taken by matter and an increase in entropy. Real substitutability is therefore not an institutional process as it exists outside of any institutional settings. What does not exist outside of an institutional setting is money-value substitutability. Money-value substitutability represents the summation of the social conditions presiding over

the action of converting coal into energy. Under free-market economics, coal will be burnt if it is optimal to do so considering consumer and producer preferences and budget constraints. It is therefore idle to try to base money value substitutability exclusively on real substitutability. The two are necessarily related, but value is needed to trigger any substitution and value requires an institutional framework which will condition actual, observed actions of substitution and hence substitutability.

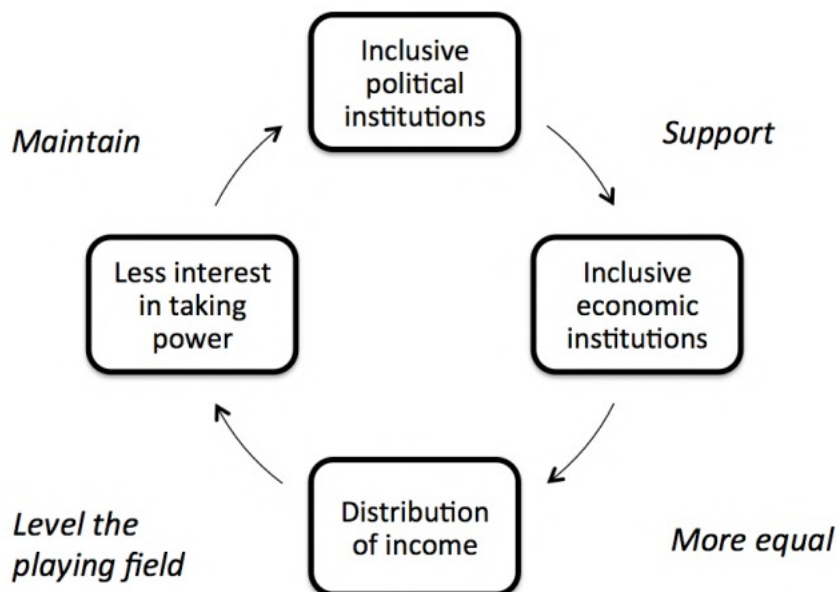
In their much-debated book on *Why Nations Fail?* [Acemoglu and Robinson \(2012\)](#) define institutions as “the rules influencing how the economy works, and the incentives that motivate people”. This definition is arguably more restrictive than the 1991 definition from North, but it fits the instrumental perspective on institutions. They use a set of historical evidence to propose a classification of institutions. They first differentiate between political and economic institutions. In a well functioning society, political institutions protect pluralism, give every citizen a say in the future of society and hold accountable political leaders. Well functioning economic institutions give opportunity, foster innovation and propel a merit-based society via the encouragement of creative destruction. They make for the best possible allocation of resources. Well functioning political and economic institutions are defined as “inclusive” and those undermining those desirable properties are “extractive”.

Inclusive political institutions protect inclusive economic institutions (property rights, patent system) which encourages innovations. From a systemic perspective, inclusive political institutions encourage pluralism and many different ideas lead to innovation through confrontation and creative destruction. They also secure a large distribution of power, which prevents one group from becoming powerful enough to overthrow the system, or even one group to become powerful (economically rich or ideologically dominant) enough to have an interest in overthrowing the system. Inclusive political and economic institutions trigger a virtuous circle of development (see figure 1.5). The authors stress the distribution and redistribution of income as a key element of stability in the virtuous circle.

Institutions tasked with organising the level of the redistribution of means, in the usual functional separation between allocation (to the economic institutions) and redistribution (to the political institutions) are therefore critical. Inclusive institutions preserve the equilibrium between the pledge of greater wealth to innovators and protection of the place of the less well-off. A system of checks and balances illustrates this tension: there should always be a power to stop another power.

On the contrary, extractive institutions concentrate economic and political power into the hands of an elite, or even a single absolutist leader. Extractive institutions are well-structured and very rigid and usually, by nature, present a high level of centralisation (at least com-

Figure 1.5: The virtuous institutional circle



Source: ?, representation from the author

pared to the institutions they replace). This is the reason why they tend to spur growth in the short/medium run after implementation. But, as by their very conservative nature they discourage if not forbid creative destruction and the emergence of competing economic and political forces, they tend to reach a stalling point, if not stagnation, degrowth or impoverishment. The last important feature of institutions is centralisation. Institutions governing a social group need a high enough degree of centralisation to make sure enforcement is possible. Rules, laws and customs have limited impact if not enforced.

Other interesting contributions in the book are the ideas of critical juncture and institutional drift. The institutional drift is a phenomenon of institutional evolution. Very few (if any) institutions are completely stable and unchanged over long periods. Most evolve via a slow process of sedimentation. A small difference at one point can result in a major institutional difference a century later. A critical juncture is a game-changing event (such as the discovery of the Americas, the industrial revolution or the emergence of Islam). When a given set of institutions in a given social group is exposed to a critical juncture, institutions will adapt, and depending on the form of the adaptation, the social group may change course completely, for better or worse. A critical juncture is a chance to change, an opportunity to seize. Societies using this shock to increase the inclusiveness of their institutions thrive (as in England after the Magna Carta) while others ultimately stall and crumble (as in the USSR).

Although probably simplistic for specialists of the field, this functional analysis of institu-

tions is quite operational for economics and sustainability. The reality of the concept of society is often debated in economics as utilitarianism only considers individuals¹⁴ and individual interests. It sheds in our view a very interesting light on the issues of sustainability and has been recognised as such in the literature on the resource curse (Van Der Ploeg 2011). The literature on the resource curse investigates the negative relationship between resource abundance and economic growth. Purely economic explanations for the relationship will be detailed in chapters 2 and 4 but the resource curse can seductively be explained in the context of extractive institutions. ? cite as an example the enforcement in the 16th of forced labour by the Spanish in modern day Bolivia. The prevalence of this institution entrenched inequalities and rent seeking in society, making optimal management of resources in Bolivia impossible.

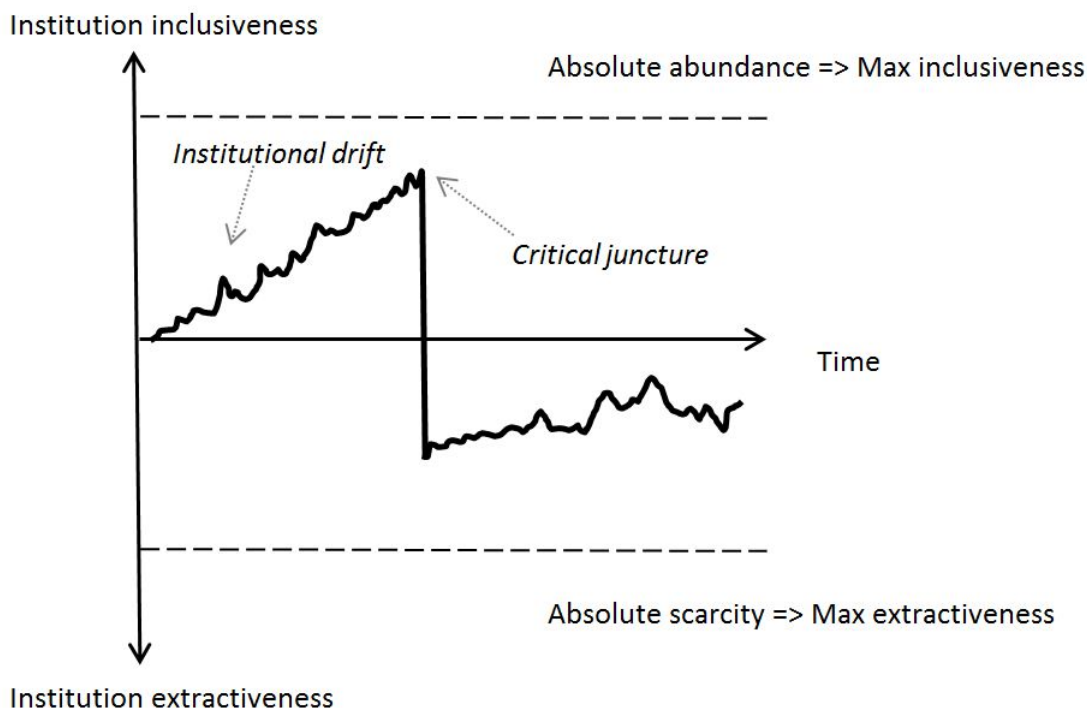
Still, extractive institutions cannot thrive without value to extract. They can stay stable for a long time, but are very vulnerable to external technical shocks, conquest and more generally to critical junctures. Sometimes, the source of value just disappears (as when Europeans managed to short-circuit Islamic routes of trade) and the institutions based on it crumble. The period of institutional re-composition can be long and dramatically painful, especially if the government collapses in the process and centralisation is reduced.

There is however a danger in considering any sustainability issue only through the institutional lens. Acemoglu and Robinson focus on exhaustible resources, and seem to see the environment as a mere external factor on which human institutions are being applied. The case they cite, on the population of North America by the English, is here particularly interesting. Acemoglu and Robinson claim that although the English tried to implement institutions similar to the extractive system enforced by the Spanish in the Caribbean and South America they failed. They explain this failure by the low population density that tilted the balance in favour of the newly arrived colonists against the ruling English elite. As colonists could just go settle outside of the areas ruled by the English, the elite had to relinquish some of its political power to make the colonies attractive enough. They make a similar case for the penal colony in Australia. It strikes us as obvious that in both cases, it is not so much the dynamics between the colonists (and prisoners) and the elite that shaped the institutions, but the shift of bargaining power introduced by the very nature of the environment. In those extreme cases, the environment was not only a feedback mechanism, but the main driver of institutional design. As is often the case, the limiting factor gets the last word.

Institutional design and evolution is the product of a mix of factors, in which economics

14. A recent illustration was given again during the American presidential election of 2012. The running president Obama declared during a speech about infrastructure and institutions “you didn’t build that” talking to American entrepreneurs. This sentence started a storm in a teacup as entrepreneurs are more prone to believe that “there is not such thing as society” to maintain and build those institutions and infrastructure.

Figure 1.6: Institutions and resources



Source: Author

plays one role. As long as a society stays within the limits of absolute scarcity and absolute abundance, then institutions are mostly shaped through drifts (see figure 1.6). When, either because of a drift or a critical juncture, institutions reach the upper bond, the access and distribution to resources is such that extractive institutions cannot survive. Conversely, when resource scarcity is absolute, the power of those having access to those resources grows exponentially and institutions turn instantly extractive. If resources are too scarce, obtaining them becomes the sole purpose of institutions (to prevent starvation for example) or if they are plentiful, no resolution mechanism is needed as there is nothing to allocate or struggle for, anyone can meet their needs costlessly.¹⁵ The most common situation is observed when resources and the environment are relatively scarce, so that people can't evade the constraints they pose on consumption and maintenance of living standards and therefore have to meet, argue and struggle over those resources and modify resolution mechanisms and institutions accordingly.

Institutions play an important role in explaining why resources are managed the way they are. The development of new inclusive institutions is a necessity to improve future management. But the role played by the environment on institutional design should not be underestimated, especially in the context of absolute scarcity. Sustainable development is constrained by sus-

¹⁵ The scenario is explored by Skidelsky and Skidelsky (2012) as presented in The Financial Times Alphaville Blog: .

tainability precisely to avoid this particular path. But sustainability does not exist without inclusive institutions. It is therefore essential to comment briefly on the links between intra-generational equity and inclusive institutions.

We saw in section I.1 how the DHSS model leads to the dissociation of intergenerational and intragenerational equity. The task of monitoring intragenerational equity is left to a redistribution mechanism, which force depend on country policies. A potential problem to this view is that assuming that the Rawlsian argument about the “original position” does not prevail, there is a strong possibility that income, wealth or both are asymmetrically distributed in a given country. Asymmetric distribution of wealth or income will reinforce extractive economic institutions, which in turn is likely to lead to extractive political institutions. Therefore, the Rawlsian argument for justice and intragenerational equity is also of instrumental value for sustainability. A skewed distribution of wealth or income can only negatively affect the inclusiveness of institutions and put sustainability in jeopardy.

Institutional design is key to sustainability, but many institutions are formed endogenously in an informal fashion. They usefully complete market mechanisms in their allocation duties when property rights are ill-defined or proper enforcement is impossible. Pargal and Wheeler (1995) show “informal regulation” to be important in Indonesia, as a way to express local preferences in terms of pollution. Informal institutions in general improve social ties and reinforce formal contracts through the building of trust. Informal regulation is one of the reasons behind the effectiveness of decentralised resource allocation mechanisms. Allocation tasks are better treated at the institutional and spatial level where information about preferences, resources, technology, etc. are best known. This means that allocation decisions should be taken at the smallest possible scale as defined by the need to collect required information.

This makes the case for an organisation based on subsidiarity. Allocation decisions should be undertaken at the level where the risk of institutional capture is the lowest. It is the lowest when no more than the required resources are involved in the allocation and the preferences of all the interested agents, with an equitable say in the process are best known. Subsidiarity is therefore the rule of spatial and institutional organisation best suited for sustainability as it protects and fosters inclusiveness. With this emphasis on the need for subsidiarity to foster inclusiveness, we conclude our presentation of the instrumental value of institutions. We have all the tools needed to assess the states of the world. We now need to turn to the issues raised by the characterisation of development paths, and the properties associated with a particular state of development: the steady-state.

Box 1.4: Real/money value substitutability and subsidiarity

Substitutability is probably the main issue between environmental and ecological economics. It sets the line between proponents of weak and strong sustainability (Neumayer 2010). Real substitutability depends on physical factors, when money value substitutability depends on allocation mechanisms. The degree of substitutability between instruments of wealth depends on the social limits sets to intergenerational and intragenerational equity. At such, it should be considered when assessing sustainability. A social, institutional organisation is best able to produce efficient allocation under a decentralised structure of allocation mechanisms. Those mechanisms, market and non-market, are better able to reflect preferences and resolve information issues at a geographical scale that matches the allocation problem at hand. Doing so prevent biases introduced by excessive concentration of political or economic power and makes enforcement easier based on a better perception of common interests and common informal norms.

Box 1.5: Intergenerational and intragenerational equity in institutions

Institutions are the favoured vehicle for intergenerational equity as institutions usually last over several generations (especially the formal ones). Well-conceived institutions, build on a shared conception of the ends of development should support the ethical commitment to intergenerational equity. But those institutions could be undermined by a drift away from equity and turn slowly into extractive institutions. To prevent this, intragenerational equity should also be guaranteed. An equitable distribution of wealth in each generation is required to create the incentives to maintain economic and political inclusiveness. Intragenerational equity is instrumental to sustainability and sustainable development, as much as it can be one of the ends of development.

II.2 Steady-State economics

This section on steady-state economics is not meant to cover the topic exhaustively. Our aim is merely to expose the issues associated with the concept of steady-state and how those issues impact the definition of sustainability. We saw how the treatment of time in sustainability requires first to define states, which can be characterised using indicators of the dimensions of interest in sustainability. It is then necessary to characterise paths, which are defined by the evolution over time of the values associated with the dimensions in the states. If one defines a given state by a value v for consumption, the path will be defined by the evolution of v values that may lead to this state. It makes intuitive sense that a path needs to be bounded by two states, defining initial and terminal conditions. The three together define transitional dynamics between two states.

Optimal control theory, whether Bellman (1957) equations or the Pontryagin maximum principle establish paths that maximise or minimise the values characterising the path and can

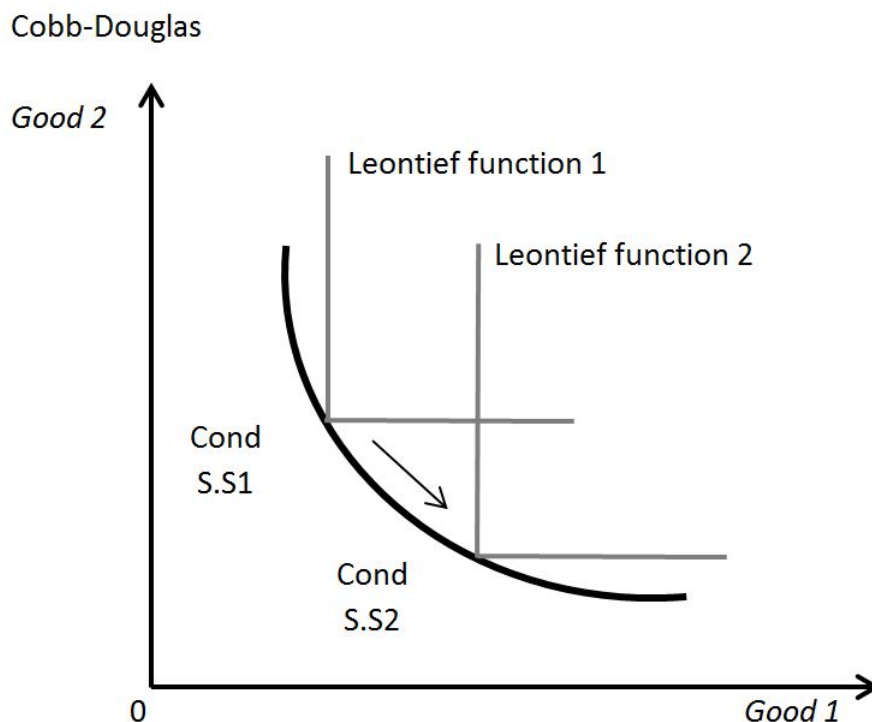
therefore qualify it to optimality. Optimal control theory is about the selection of one path out of a potential infinity. Used in the model, paths and states selection and definition require the selection of those characteristics amongst the multiplicity needed to exhaustively characterise a given path. This is a major hurdle. In economics and sustainability analysis, those paths are usually explicitly constrained, using for example a budget constraint. The implicit assumption is always made that the path is also constrained by the many excluded characteristics that were not selected to define the path. Institutions are usually implicit constraints (assumed constant) to an optimal growth path.

In economics, optimal growth theory is used to define convergence towards the steady-state, a particular state with desirable mathematical properties of uniqueness and stability, mirroring the properties of the economic general equilibrium. The path from a randomly chosen (or more commonly set at the current conditions) state to the steady-state is then assessed and commented. Considering the desirability of the steady-state, the most common modelling strategy is to *assume* that the economy already converged to the steady-state and then study how under a given shock, the economy will return to this steady-state. This choice is motivated by both the mathematical convenience and the economic properties of the steady-state.

This strategy is sensible and justified in economic models. Those are and will remain simplified representations of the reality. More problematic would be a tendency to confuse the results of a model with an accurate representation of the reality. Even more problematic would be a tendency to let the constraints set by available modelling tools shape perceptions of the reality. A first warning for this comes for example in [Hicks \(1946\)](#) where he explores the dangers associated with ignoring the “short term” in economic analysis. Some economic relations may hold in the short run because of uncontrolled characteristics, and not in the long run or vice versa. As reported by [Cohen and Harcourt \(2003\)](#), Robinson insisted during the Cambridge/Cambridge controversy on the difference between difference and change. Comparing two states of the world without regard for the evolution implied to go from one to the other would be simplistic. One should at least provide a presentation of the dynamics, of the characteristics of the path to get there. An illustration of that problem is given in [figure 1.7](#). Consider the difference between A Leontief and a Cobb-Douglas production. Transition between the conditional steady-state 1 and 2 will take the form of a gradual change in the Cobb-Douglas case. It is only possible through an instantaneous jump in the Leontief case.

[Georgescu-Roegen \(1971\)](#), writing at a time when optimal control theory already offered a potential answer to this problem, insisted on the qualitative dimension of a path. The notion of process underlines the incremental nature of evolution and the need to consider an adequate time frame for great changes. The fact that an optimal path defined by some characteristics

Figure 1.7: Difference and change



Source: Author

exists does not mean that the path is achievable in the considered time frame. This could be either because real life processes do not exist, demand more time, or are simply inhibited by unobserved characteristics. This is a powerful argument to introduce two critical elements for sustainability. The first element is the likely existence of multiple equilibria, many potentially satisfying steady-states because of the dynamics of a given problem or a change in initial conditions. The idea that the same problem may lead to a different solution depending on initial condition is an especially severe blow to the neoclassical theory. The second element is the potent role of uncertainty in shaping outcomes. If the steady-state is determined by the path used to reach it, there is “path dependence” in the economy. The opportunity to use current value indicators is greatly diminished as those would be conditional to the realisation of the whole path. A single shock would change the steady-state and cancel any validity for the indicator.

The dynamics are obviously critical to sustainability and those objections do not mean that optimal control theory cannot be used to assess them. It is just important to realise that the possibility of persistent disequilibria compared to a given steady-state is real. It also means that the higher the number of potential paths (and ideally conditional steady-states) considered, the better the understanding of the problem at hand. Those objections also make a case for the

study of transitional dynamics from a variety of original conditions to steady-states, in departure of the usual practice of studying departure from the steady-state. The notion of steady-state is employed quite ambiguously in sustainability studies. In the weak sustainability paradigm it refers to the neoclassical steady-state in its somewhat evanescent conception. Economies still experience growth in many dimensions, when neoclassical economics focus on the moment when those economies will be at the steady-state.

Faced with this ambiguous position, most ecological economists followed [Daly \(1996\)](#) who calls for “true” steady-state economies and the logical end of growth. Path dependence and technical progress may explain this. Environmental economists revise regularly their vision of a steady-state for the means of development mostly because of technical progress¹⁶, when ecological economists tend to focus on presently available means and have a much more stable perspective on the steady-state. This makes for probably too pessimistic views on the future in ecological economics and too optimistic views in environmental economics (see section [II.2.1](#) below).

So, is there an end to development, a “Greek” steady-state from which societies would only depart for the worst? The weak sustainability paradigm does not seem to think so, although the perturbations introduced by dysfunctional market mechanisms and societies are studied in numerous contribution. [Dasgupta \(2001\)](#) proposes a difference between *Agathotopia* and *Kakotopia* to describe the difference between a well-functioning society and a dysfunctional one. Those two societies would naturally converge to different steady-states even with similar characteristics. In our view, this makes the case for using sustainability rules and scenarios to assess the consequences of allocation decisions on the steady-state. Sustainability rules such as the Hartwick rule should in this setting not be followed to the later but as a benchmark to assess a “distance to an optimal path”.

If development is a cumulative, drifting process, then present uncertainty about the future is compounded by the uncertainty introduced in future periods. [Heal \(1998\)](#) presents the debate over the use of different discount rates to measure this uncertainty. The most natural solution, a time varying-discount rate, leaves the analyst facing a major trade-off between added complexity and added analytical power. Although discussions over the discount rate may prove fruitful and reduce uncertainty, it seems unlikely that the margin of error over the very long run might be significantly reduced. It seems more promising to us to focus on the problem of short to medium term consistency. Introducing time dependence in the discount rate is helpful if the structure of the model is constant over time. But if functional relations are also time dependent, then the best strategy is to build different models for different time horizons and

16. Although path dependence may play a bigger role.

make sure that those models are consistent with one another.

The ineffectiveness of sustainability policy is usually put on short-termism at the scale of a century or more. This is especially true for climate change studies. In fact, time inconsistency is much more of a problem for shorter horizons. A political cycle lasts on average five years, a generation thirty years, a life in employment between forty and fifty and life expectancy in developed country now flirts with eighty-five years. Sustainability development policies can only be implemented under time consistent settings at the political and generational scales. Lack of time consistency over the next five to ten years makes a thirty or sixty years target impossible to hit. There is an inevitable tension between the need for consistency and the legitimate desire of new generations to explore their own options regarding development. We offer the idea that subsidiarity and our narrow definition of sustainability offer a way to minimize this tension. By separating the management of the means from the definition of the ends, the room for inclusive institutions over the definition of those ends can be preserved. Subsidiarity may also help to reduce constraints on the definition of the ends by limiting the scope of sustainability constraints to their relevant scale. At the same time, subsidiarity imposes limits on the potentially damaging consequences of ill-defined ends which may exceed sustainable limits.

A single current value indicator, even completed by several scenarios, cannot reflect on all the characteristics of a state. Assessment of present institutional inclusiveness, observed substitutability, etc. should all be part of a broad assessment of sustainability. Finally, beyond indicators to monitor sustainability, other indicators are needed to monitor the realisation of the social ends in development.

Box 1.6: Consequences of uncertainty and path dependency for sustainability: the precautionary principle

The mathematical tools at our disposal do not allow for either an unequivocal definition of a steady-state, nor an exhaustive inventory of the path leading to a given constrained steady-state. Uncertainty and path dependence call for precaution regarding future substitutability, as non-linearities in the development path prevent extrapolation based on current levels. Still, uncertainty can be mitigated by a clear definition of the scope of sustainability and an application of the subsidiarity principle. Subsidiarity creates room for decision making at local scales, while reducing the impact of local mismanagement. Uncertainty over the rate of wealth accumulation makes intragenerational equity more important, as present generations cannot count on the preservation of their relative political and economic influence in the next generation. Climate change illustrates how uncertainty makes the consideration of future generations critical as the impact of present actions on future generations becomes harder to forecast.

II.2.1 Is a single indicator of sustainability enough?

The use of multiple indicators in sustainability derives from the need to offer a complete characterisation of a state (steady or not). Problems arise when trying to differentiate between characteristics that are only instrumental to sustainable development and the very ends of it. The need to make this distinction is usually brought forward by proponents of a single indicator for sustainability. What matters is to monitor the ability of the economy to support the ends of development and then other indicators can be used to monitor the fulfillment of those goals. As shown by [Dasgupta \(2001\)](#) the use of multiple indicators to assess the ends of development is quite consensual as those ends reflect the multiple dimensions of the human existence. As documented in [Neumayer \(2010\)](#) the debate over the use of more than one indicator of sustainability comes from the controversies over substitutability. In a weak sustainability perspective, the only thing that matters is the maintenance of the overall productive base, assessed by the contribution of all the instruments of wealth in the economy. One indicator to monitor the level and variation of total wealth is then enough. But if there is uncertainty over substitutability, then several indicators may be required to assess the contribution of all instruments of wealth separately and the possible substitutability between those instruments.

This is the view taken by ecological economists. When doing sustainability assessments, most authors in the paradigm argue for more than one indicator. [Martinet \(2011\)](#) presents the difference between criteria and indicators: criteria are usually variables or conditions taken from a model, whereas indicators are characterised by intervals and thresholds calling for policy action. [Heal \(2011\)](#) presents several indicators and stresses the need to go “beyond GDP”, insisting countries adopting Hartwick rule-like policies were already seeing the positive results. A similar call is made by [Kubiszewski et al. \(2013\)](#) who compare several indicators against GDP for seventeen countries. [Nourry \(2008\)](#) assesses sustainability in France using ANS, GNNP, the ecological footprint, the Indicator of Sustainable Economic Welfare (ISEW), a pollution-sensitive HDI, the Sustainable Development indicator and the French Dashboard on Sustainable Development. She concludes that France is sustainable in the weak sense but not in the strong sense between 1990 and 2000 and that the Dashboard approach is probably the best. A similar conclusion is reached by [Musson \(2013\)](#) who review several indicators in her effort to combine sustainable development and attractiveness. [Mayer \(2008\)](#) pointing at the well-known potential flaws of index and aggregated measures also favours the use of a dashboard of indicators to be weighted in the decision process by policy makers. This is even more important as often indicators draw opposite conclusions, as showed by [Ollivier and Giraud \(2010\)](#) in the case of Madagascar. [Pillarsetti \(2005\)](#) criticised ANS on the ground that it leads to the wrong policy regarding sustainability.

The quest for “the” indicator of sustainability is probably endless but authors keep suggesting new methods, empirically or theoretically grounded. [Martinet and Doyen \(2007\)](#) offered to use the viable control approach instead of optimal control theory, that is to focus on the viability of a system based on resource constraints and a minimum consumption level instead of focusing on optimality. [Shmelev and Rodríguez-Labajos \(2009\)](#) and [Shmelev \(2011\)](#) suggest a methodology for multidimensional assessments (i.e. social, environmental and economic), applied to Austria and Russia. [Kulig et al. \(2010\)](#) support the use of capital theory but call for the use of non-monetary units instead of the usual monetary ones.

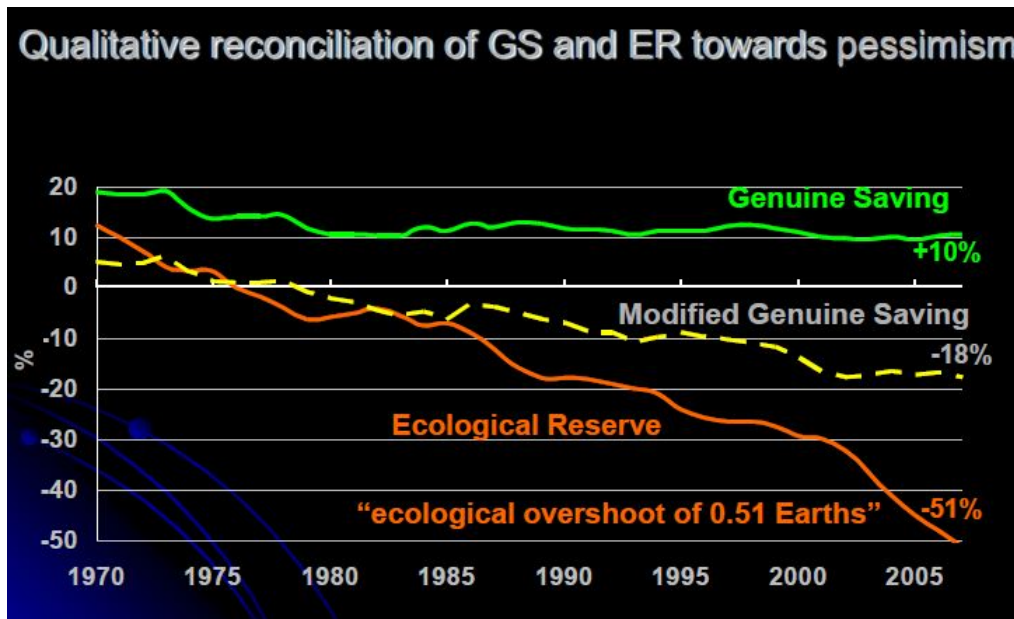
It seems that if the debate is still largely open in academia, two indicators now have the leading role in terms of sustainability assessment: ANS and the Ecological footprint. ANS have the favour of international institutions and is supported by both the World Bank and the United Nations ([Atkinson et al. 2012](#)). The Ecological Footprint is widely used in the business community and the broader civil society, especially under its “carbon footprint” declination. The point of this thesis is not to compare those two indicators. But it is worth pointing at two facts about those indicators. First, it seems that both indicators have found there audiences. The logic of the footprint makes it more amendable to consideration by a general audience. Although it is potentially subject to overshooting, in the current environmental context it seems preferable to an indicator underestimating problems. The message send by the ecological footprint is simple: the aim is to minimise it. Conversely, ANS being closer to usual macroeconomic indicators is better armed to fit in macro-management state policy. The second remark comes from [Hanley \(2011\)](#). Quoting on [Pezzey and Burke \(2010\)](#), Hanley suggests that part of the gap between the conclusions of the Ecological Footprint and the ANS is related to the pricing and the assessment of some dimensions of environmental damage.

In figure 1.8, the Ecological Reserve is derived from the ecological footprint¹⁷ and the “modified Genuine Savings” dotted line is obtained by increasing the price of carbon. It seems therefore that at least part of the gap between the two measures can be addressed by making comprehension wealth more “comprehensive”, i.e. including assets that might be under-priced today. We would add to this comment that this hints towards a potentially unsustainable level of consumption, not in the narrow sense but in the Fisherian sense of services consumption.

This comparison illustrates the complementarity between current value indicators, which can be used to assess the evolution of the productive base, defining both a state and a path towards that state, and present value indicators assessing the productive base in t . If the message on sustainability differs between present and current value indicators, it is likely that either uncertainty or actual substitutability between instruments of wealth is over (or under)

17. $ER=1-(\text{Ecological Footprint}/\text{Biocapacity})$.

Figure 1.8: Carbon pricing and indicators



Source: Pezzey and Burke (2010) in Hanley (2011)

estimated. The difference could naturally come from measurement errors, or biased valuation because of market imperfections. Still, it seems necessary to address inconsistencies between indicators as they may reflect a critical but missing dimension of sustainability in one indicator. As discussed above, we believe that the use of counterfactual scenarios can address this problem, while showing the necessary amendments to the underlying model for a given indicator. Adjusted Net Savings seems best suited as an indicator of the evolution of the means, completed by regular present value assessments for the evolution of real substitutability and market imperfections. Present value indicators are also best able to monitor the evolution of preferences, especially shifts in consumption patterns.

Those remarks conclude our presentation of the issues related to the notion of steady-state as an analytical tool for sustainability. We stressed potential issues associated with uncertainty which makes multiple equilibria likely and may bias indicators based on steady-state convergence. Multiple equilibria can also be generated by different perceptions of sustainability, as different sustainability rules may result in different steady-states. Present value indicators are then critical to reassess sustainability paths from time to time and provide knowledge of the current sustainability trajectory.

II.3 Sustainability: an integrated framework

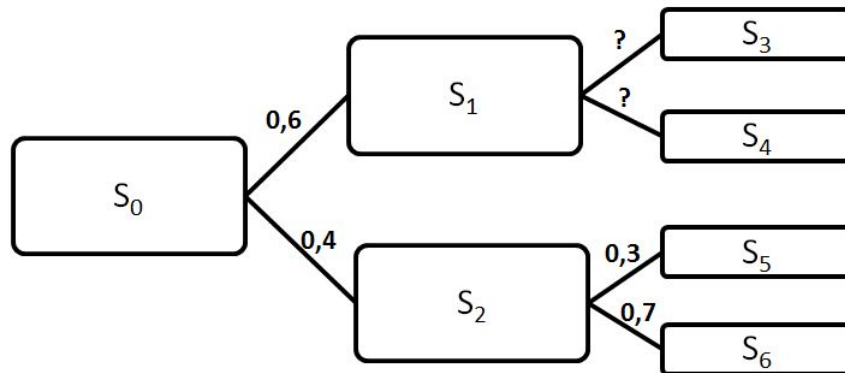
In the previous sections, we presented the building blocks of sustainability and how the theory of sustainability yields information on the state of sustainable development today. In this final subsection we will propose an integrated framework for sustainable development and sustainability. We hope it will help to highlight challenges left to be addressed in the field. This section will also be the basis of our assessment of the role of trade in sustainability. It is fair to ask why an encompassing theory of sustainability is needed. The answer is twofold. First, both the neoclassical and the ecological economics paradigm fail to address consistently all the questions of interest in sustainable development and sustainability. Second, beyond theoretical satisfaction, policy evaluation requires this consistent framework to make sense of the mass of data provided by current and present value indicators.

Sustainable development and sustainability are two different concepts. Sustainable development is the concept describing the all encompassing problem of development. Sustainable development is simply development once the possibility of unsustainable development is ruled out. Development is the process by which human beings evolve from a given state, summation of conditions and characteristics, to another. Development is to be understood as a set of goals, observables or not, decided and implemented by individuals and groups in a given institutional, legal and societal environment. Formally, development can be characterised in discrete time as a succession of states representing the state of completion of the goals set in the origin. Those conditions encompass all the dimensions of the human experience: physical constraints, institutional organisation, perception of the environment.

From a logical perspective, the challenge is therefore to define development, and then to identify conditions of “un-sustainability”. We set out several times in this chapter how development goals should be chosen by social groups and will therefore not propose any set of development goals. What matters to our presentation is a definition of “un-sustainability”. A first category of unsustainable development is development which goals are de facto contradicting the proclaimed aims of development. The (inaccurate) metaphor of the Easter island is a good illustration of this. A second category of unsustainable development is development whose goals are unattainable under a set of perfectly known current and future conditions. The great leap forward in China is the perfect example of this, where too many constraints (time and qualification of the manpower to name only two) were put on the development process to make it sustainable. The final category can only be described taking uncertainty into account.

Can be characterised as unsustainable a development that relies for the assessment and the fulfilment of its goals on elements which availability or occurrence cannot be associated

Figure 1.9: Development paths



Source: Author

with a probability. In this category are therefore developments that are *ex-ante* unsustainable and *could* be either sustainable or unsustainable *ex-post*. This sends us back to box 1.6 and the importance of precaution in the wake of uncertainty. Action should only be undertaken in conditions of minimal uncertainty. Reducing issues commanding action to a more commendable size, following the subsidiarity principle, is a necessary first step to reduce uncertainty.

Under this definition, sustainable development is therefore a development that, under all the present conditions and future conditions for which a probability of occurrence can be computed, is characterised by non-contradictory goals (i.e goals that do not exclude on another). It is at the same time a path for the goals and steps involved in the considered development that does not include at any time a situation of uncertainty regarding achievement of the goals. Those goals are derived from the set of values ruling the considered society, this very set being the product of human interactions.

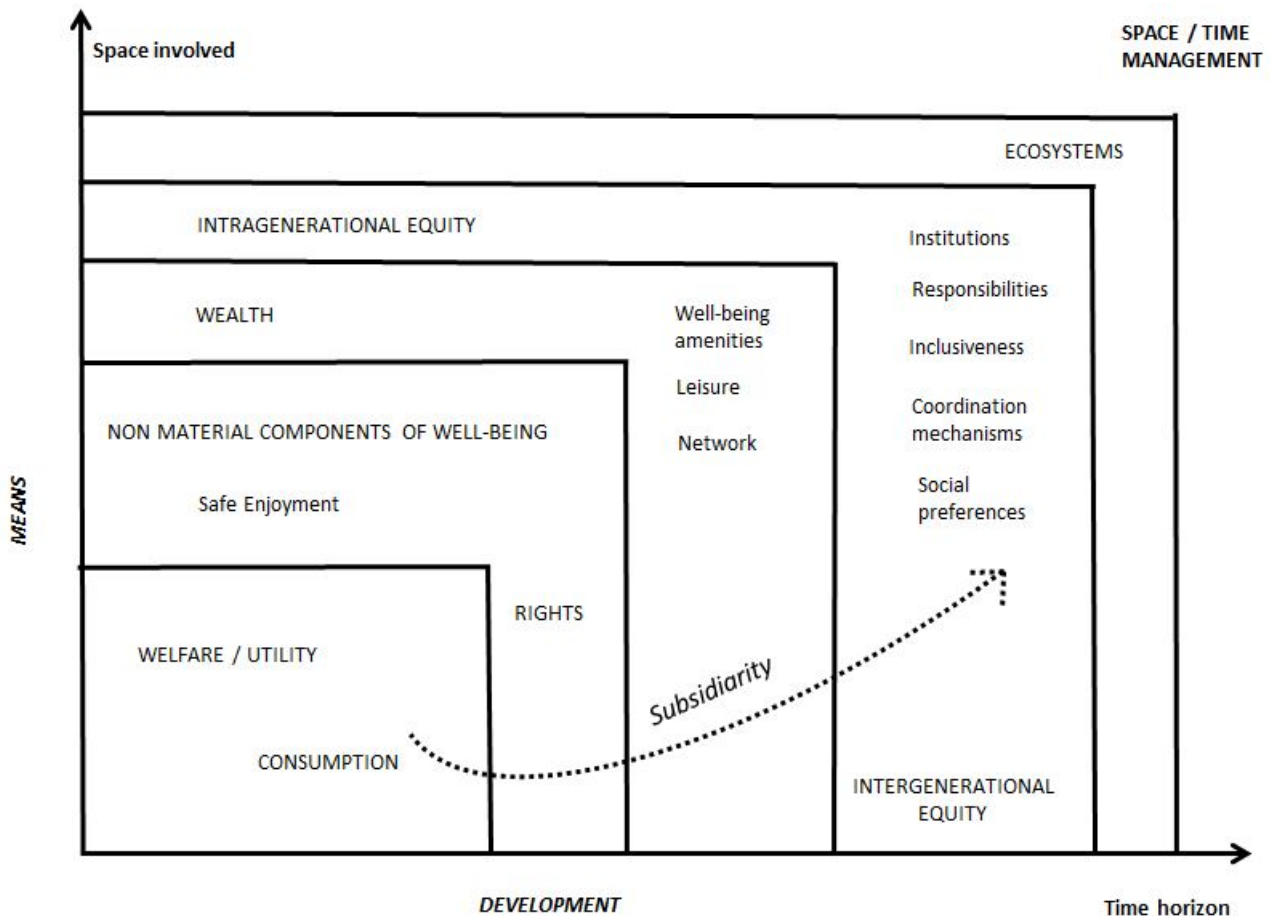
In figure 1.9 sustainable developments are composed of states S_0 , S_2 and S_5 and S_6 as any path going through S_1 ends up in uncertainty and falls back into third category unsustainable development. It may be that radical uncertainty cannot be ruled out for *any* path of development. A sensible rule would be to choose the path where radical uncertainty comes the latest. This way, present value indicators used at every step and counterfactual scenarios may allow to turn uncertainty into risk before the period of uncertainty is reached. In that sense time consistency is critical to sustainable development and sustainability. When means are mobilised to face short term development goals, this can not be done in contradiction to long run goals. This may prove troublesome in countries where either the long run goals are unclear, or the structure of power (and the timing of decisions) favours short-termism or present interests against future ones. Still, sustainable development is in essence consistency between the means and

the ends of development. Sustainable development calls for precaution in the wake of radical uncertainty. Precaution starts with consistency in means and ends over time. Respecting the precautionary principle reduces uncertainty and helps to build consensus around the definition of the goals of development.

From this definition of sustainable development, it is easier to define sustainability. Sustainability is the set of instruments of wealth (total and distribution) and rules of allocation that are compatible with the realisation of sustainable development. Sustainability is therefore conditioned by the set of values consistent with sustainable development. To phrase this differently, sustainability is the characterisation of the instantaneous or discreet conditions in t that are necessary and sufficient to achieve sustainable development. Sustainability is preconditioned by a given set of values. Those values should be consistent with sustainable development. Sustainability cannot yield a “best set” of values guaranteeing sustainable development. It can only, via the need for consistency, limit the set of potential values upheld by a given society. Dasgupta (2001) wonders whether people agree on goals (and values) and disagree about facts, or disagree on facts and therefore route for different goals (and values). A similar question is implicit when scientists (especially in natural sciences) feel frustrated by the lack of political action in the face of overwhelming evidence. Is it the political will that is missing, or the evidence that, however strong, is not yet compelling enough? Dasgupta (2001) believes it is the different perception of facts that leads to seemingly “bad” decisions. He therefore pushes for more accurate evaluation as a way to make choices more compelling.

It seems indeed hard to imagine a lack of consensus over the idea of “improving well-being” or “improving the quality of life”. But sustainable development as we defined it necessarily include values providing “upper bounds” on those abstract goals. No one is against “freedom” *in abstracto* but many disagree on the limits on individual freedom to preserve the freedom of every individual. Values do pre-condition development, and in that sense people can disagree on the relative merits of different values. Sustainable development is indeed a postulate, although a protean one. One’s vision of sustainability is shaped by it. Ethical choices are necessary. They are and should be the ultimate guide of human action. The [World Commission on Environment and Development \(1987\)](#) definition stresses what is maybe the common ethical denominator of sustainable development policies, that current and future members of a human cohort matter. They should be considered in the economic and political decision taken today. Even more than economics, sustainability economics require consistency in human decision-making and decision-taking processes. It should be clear that other human-beings matter not only for their hypothetical instrumental value, but in a more fundamental way. This postulate is one of the living expression of human dignity, a fundamental right to the opportunity of honourable existence within and between generations.

Figure 1.10: Subsidiarity and the four physical dimensions of development



Source: Author

Sustainability studies focus on the allocation of resources, also presented as the source of material well-being. Sustainability deals with the rule of proportion, ensuring the means are a match for the ends. It is concerned with ruling out unsustainable path and can produce a sustainable path under the constraint of its theory of value. In line with the concern for future generation, sustainability considers long run consistency in the management of resources needed by human societies. Considering the growing importance of uncertainty and the incremental coming of age of new generations, consistency and precaution command proportionality between the scale of the means and the horizon considered. Longer time horizons should only be applied on larger scales, and vice versa. This gives us the figure 1.10 where proportionality is more appropriately defined as subsidiarity.

Sustainability is based on the articulation of a theory of the means available to the ends, and a theory of value. The first theory rules the relations between human-beings and their environment and the second one links human needs and wants between one another. The use of market instruments and the utilitarian theory of value allows for the preservation of

individual opportunity.

Resources management requires, as presented above, a conceptual framework to organise the relationship between mankind and its environment. Capital theory *stricto sensu* is nothing if not a theory of the relations between human beings and their environment. Capital theory is build on the assumption that human-beings consider their environment as a pool of instruments of wealth. This has been translated later into the characterisation of capital as productive assets. Fisher's definition (anything that is material and can be owned) is less restrictive. His analytical framework based on services, wealth and outgo provides us with a way to link the wants and needs created by the human mind to the environment. The environment is then redefined as potential and actual instruments of wealth, generating services and needing disservices/maintenance to deliver.

This very general definition has the great advantage of solving, at the conceptual level some of the objections raised by the proponents of strong sustainability. Any item providing services to humans is wealth and therefore the question of ecosystem services is solved in this context: ecosystems are valuable and needed as even if humans do not always realise it, they provide services, are part of wealth and should therefore be maintained (in this case protected) to be able to keep providing the services. Different perceptions regarding the value of an instrument of wealth are possible. Even what is regarded as non-productive can be valuable. Property right regimes are the precondition of value, as property creates the possibility of action, and action the possibility of a flow of service. Much more than productivity, it is property that defines the relationship between humans and their environment, and therefore capital theory. Creating explicit property rights and ownership is a powerful way to distribute responsibility for wealth. With explicit responsibility and reward will come better management of wealth.

The definition of Fisher needs only to be completed for the new immaterial forms of wealth, such as software, which can be owned and leased but are not material. They are however a form of wealth, as they are a new source of services for the human mind that Fisher could not possibly imagine. From this, we draw this imperative of the preservation of the productive base, in the broad sense of instruments of wealth as capital. Only when the perimeter of capital is clearly established should a theory of value be applied. Starting here and to avoid future confusions, we will use the following terms to differentiate between the instruments of wealth:

- Produced capital refers to capital as defined in the mainstream economic literature. Produced capital is exemplified by machines and more generally investment goods and services. Produced capital also includes the growing immaterial assets (brands, software).
- Natural capital is the sum of all the assets available in nature and form the environment in which human beings evolve. Natural capital can be divided between ecosystems and

resources and again between renewable and non renewable resources.

- Human capital represents the direct contribution of labour to the production process, plus the general contribution of education to collective well-being (better law enforcement, etc.)
- Institutional capital is the instrumental value of the rights and responsibilities defined by the institutions. This instrumental value is a form of wealth as it adds up to the value of material consumption.

Wealth represents the sum, the entirety of the material and immaterial assets and capabilities available in a given geographic and social object. Wealth is instrumental to development, as it represents the resources, of any nature, available to a group of human being to achieve development. From the presentation of [Hicks \(1946\)](#) in the introduction, it is clear that the concept of income can be problematic. However, the distinction between gross and net income is important and solves many potential issues. Beyond raw accounting it stresses the responsibility of wealth owners regarding the maintenance of any form of capital (see chapter 4 section III).

Resources management then requires a conceptual framework to allocate, distribute the resources henceforth identified within society. This theory of value should aim at allocating the services from instruments of wealth in an optimal fashion. This theory of value should be guided by ethics. An ethical position consistent with sustainable development commands that the optimal allocation is fair for current and future generations. Utilitarianism is shown by [Solow \(1974\)](#) and [Dasgupta and Heal \(1974\)](#) to create Pareto-optimality within and between generations. Fairness or justice proved harder to be put in the theory. Arrow's argument about the inequality between generations necessary to capital accumulation is powerful and proved sufficient to shift the burden of fairness away from allocation to redistribution. Poverty reduction by growth in the most destitute parts of the world shifted the emphasis on creating the conditions for growth, and therefore on promoting non utilitarian components of well-being (rights and capabilities). Giving people opportunity and rights where they were needed most would make everybody better-off. The use of market instruments and the utilitarian theory of value allows for the preservation of individual opportunity while guaranteeing inter-temporal optimality.

The difference between money-value substitutability and real (physical) substitutability is here critical. Physical substitutability is modified by technical progress, the human ability to create or restore a given ecosystem. As money-value rests on ethics and principles, allocation mechanisms never reflect substitutability in its physical dimension. Money-value can only reflect the perception of scarcity, the evolution of substitutability with respect to "present and/or current value" human needs. Uncertainty will always prevent money to be a "seamless"

instrument of wealth and market mechanisms to reflect physical substitutability. From this conclusion, either the neoclassical theory of value needs to be amended, or market mechanisms need to be completed by other institutions.

Capital theory and utilitarianism combined ensure consistency under the assumption of a complete set of markets. Those theories knew several ramifications since they were first formulated. Knowledge expansion is a process that is neither predictable nor exempt of stagnation or regression. It is useful to get back to the branching out point, the “common ancestor” to understand the original intention and therefore the current applicability of a concept. In the case of capital theory, it seems that Fisher’s vision of capital is more operational in the current context than the now conventional “productive” view on capital. Capital theory and utilitarianism give a clear scope for sustainability. Sustainability formulated on the basis of those two theories yields principles for sustainability assessment. The current integrated model of sustainability (the DHSS model) produces three criteria:

- Constant consumption in value over time
- Maintaining global productive base over time (weak sustainability) or maintaining each component (strong sustainability)
- Intergenerational equity: apply the consistency principle

We insist on the central role of precaution in dealing with uncertainty on the development path. Precaution leads to proportionality (or subsidiarity) in scale and time when tackling development issues. Proportionality and precaution are hard to incorporate in sustainability theory because they can either be sourced in efficiency concerns or in ethics and values. In the first case they should be incorporated in a more comprehensive theory of value and in the second case they come into well-being as a non material component and therefore are not a sustainability concern. The DHSS model and the literature on sustainability do not make claims about precaution. Subsidiarity can be understood as nothing more than the usual constitution of decentralised markets. But in the context of sustainability, the call for decentralisation rests on more than efficiency (and inter-temporal consistency). Subsidiarity in sustainability is also about precaution. Tackling issues at the relevant scale leaves room for policies best fitted to local preferences, but also to the possibility of experimenting and amending sustainability policies over time. In that sense, subsidiarity is key to equity and efficiency.

Subsidiarity is also important for substitutability. Fisher (1906) did not make any explicit assumption regarding substitutability, but capital theory is clearly based on the logic of perfect substitutability. The strong sustainability critique appears therefore very relevant as the actual degree of substitutability between different instruments of capital is at best estimated to be high but not perfect (World Bank 2006). Neumayer (2010) makes it clear that actual substitutability

is the main, if not the last real difference between weak and strong sustainability paradigms. However we argue that the critique is not incompatible with capital theory and the definitions adopted above. In Fisher's theory, perfect substitutability is based on the use of money funds to transfer seamlessly stocks of wealth. In capital theory, it is not technical, entropic or physical perfect substitutability that is assumed, but value-substitutability. Money being neutral in the neoclassical sense, it is a perfect instrument to this end. But nothing in the theory prevents us from barring some form of conversion from one instrument of wealth to another, or impose a penalty on such a conversion. Assuming we can produce an estimate of the degree of physical substitutability (as an objective base) then instead of a system where 100 units of wood can be converted to 100 units of chairs and then to a 100 units of paper, one can imagine a system where 100 units of wood can be turned into only 80 units of chairs but into 90 units of paper.

Quasi religious faith is placed on technical progress today, many arguing that only a new industrial revolution can bring the technical tools to solve sustainability issues. But the limiting factor is in most cases not the technical feasibility of a given project. Studies such as [Jacobson and Delucchi \(2011\)](#) and [Delucchi and Jacobson \(2011\)](#) exemplify this. If technical progress was always the limit, then no allocation mechanism for investment would be needed as the best project would always be the obvious choice. The basic problem lies in the distribution of wealth with respect the the relevant scale and the lack of adequate allocation mechanism when this is not the case. Beyond the design of complete markets to narrow the gap between market and shadow prices, a more fundamental rethink of the role of money-capital is essential. Money capital is filling too many roles today, being trusted to be both the neutral neoclassical tool and a policy instrument to control the business cycle. A fine demonstration of this is inflation. In a money-neutral setting inflation yields an information about economic substitutability. But in the current context, inflation is determined by a wide set of factors, the most prominent being money creation by commercial banks. To solve this problem, one should solve the paradox that money is money because it is liquidity, and liquidity is the reason why money cannot be used for its theoretically core function: indicating substitutability.

Subsidiarity is the "missing link" between the short run and the long run. When confronted with issues lasting over time, one should neither loose sight on the long run or the short run. Guaranteeing opportunity to each generation involves making sure that no one is left behind in the current generation. If so, increased compensation is needed for future generations by the better-off in the previous ones. Therefore, a final principle of intragenerational equity is needed, to correct short run discrepancies that have cumulative impacts in an accumulation process. The vision of what the long run equilibrium is can be quite different depending on the starting point chosen for the analysis. This situation is strikingly similar to the pictures drawn by ?. Extractive institutions will soon emerge from the growing concentration of wealth in the

hands of an ever tinier minority.

Therefore, if one subscribes to the need for inclusive economic and political institutions as a way to maintain desirable elements of well-being (both material and immaterial) then one should also subscribe to the ethical imperative of intragenerational equity. Intragenerational equity is both an indicator of institutional inclusiveness¹⁸ and one of the necessary values of a sustainable development path.¹⁹

Another way to define the imperative in terms of consistency is to think of an overlapping generations model. If one defines the theoretical length of a generation to be short, at least shorter than life expectancy then generations will overlap. Assuming that the new generation is better-off thanks to capital accumulation, then people leaving at the same time but belonging to different theoretical generations may have quite different levels of wealth. We can therefore conclude that intragenerational equity is the first step towards intergenerational equity, as both imperatives may merge in an overlapping generations setting. Inclusive institutions and intergenerational equity both aim at preserving opportunities for all individuals in one generation. If sight is lost of this imperative, then numerous unsustainable paths can be chosen as they maintain consumption at least constant over time, but fail to keep relative equity in opportunity constant.

Potential links between intragenerational equity (income inequalities) and intergenerational equity (environmental issues) have been studied mostly in the wake of a possible Environmental Kuznets Curve (EKC, see chapter 2 section I). An early contribution by Boyce (1994) proposed as an hypothesis that inequalities in wealth and power would lead to higher environmental degradation. Scruggs (1998) tried to test the hypothesis and failed to obtain a clear cut relationship between income or wealth inequalities and the environment. Although the tests of the relationship are conducted in cross section, results suggest that structural characteristics (first and foremost political institutions) are critical. Torras and Boyce (1998) reach a similar result, showing that the political structure (civil and political rights) weight strongly on the relationship. Those studies predictably stress the need for political inclusiveness to foster environmental awareness. Intragenerational equity and inclusive institutions are again the basis for intergenerational equity.

Intragenerational equity helps with a wide range of problems as increased downside power allows for increased efficiency under the subsidiarity principle. Intragenerational equity there-

18. When intragenerational equity is understood as an equitable share of the return on overall wealth. It then warrants access to the political process and the economic institutions via investment.

19. When intragenerational equity is understood as equity in opportunity from birth throughout life, as in Rawls (1971).

fore scores on both improved efficiency and consistency in institutional and economic organisation, improving sustainability and equity. It also makes enforcement of property rights regime easier, providing more adequate means of protecting property for the worse-off. It is also worth noting that intragenerational equity helps addressing the issue of discounting, at the core of intergenerational equity issues. The standard criteria as presented for example in Dasgupta (2001, p. 24) is to choose current and future states according to Pareto-optimality. In this setting, the pure rate of time preference is critical as it states the preference of current decision makers along the path over an infinite amount of time.

The long distance debate between Ramsey (1928) and Solow (1974) settled for a relatively high rate of discount of future generations. In this context, the more likely it becomes for future generations to face daunting challenges (such as global warming) the more the current generations should save. A strong intragenerational equity reduces the size of this provision, as inclusive institutions provide a better buffer for the majority. In a similar vein, short term shocks may require the conduct of short run adjustment policy that may prove inconsistent with the long run sustainable path of development. Intragenerational equity reduces the size of this adjustment, which proves to be politically and economically harder to implement. The consistency (and therefore efficiency) gains of intragenerational equity should not be underestimated, although they are, like any counterfactual gains, hard to estimate.

In the conceptual perspective of this section those conflicts between short run stabilisation and long run optimality need not arise, but neither is there anything to prevent them. Therefore, the allocation system that would complement or substitute to the neoclassical theory of value should have built in either an allocation compatible with both intra and intergenerational equity, or an allocation and a redistribution mechanism. The general course of the field has been to separate allocation and redistribution, and to promote the development of market mechanisms for the former and redistributive institutions for the later. This strategy has so far failed to produce a state of greater equity, at least in income distribution. If the operational distinction between primary allocation and redistribution fails to produce an outcome consistent with a sustainable development, then an alternative should be found. Our demonstration suggests that the weight does not rest on the shoulders of capital theory. It is a theory of value consistent with both intergenerational and intragenerational equity that is needed. We think this is the key behind the theory of “social interactions”, the missing link in the model presented by Arrow et al. (2010). In the meantime, it is to say the least troubling to be more worried about the future of a distant generation compared to the worst-off elements of the current generation.

This concludes our attempt to propose a conceptual definition for sustainable development and sustainability. We stressed the importance of an all-encompassing capital theory to define

the relationship between human-beings and their environment. We then presented the limits of the current theory of value and highlighted the role of intragenerational equity in solving issues regarding the internal consistency of the theory, especially regarding sustainability and the time horizon. It seems that incorporating intragenerational equity in the theory of value associated with sustainability is the next frontier for research in the field. This is certainly the key to the maintenance of the virtuous circle (see figure 1.5) promoted by ?. We propose five dimensions for sustainability assessment:

1. Maintaining comprehensive wealth over time, that is preserving exhaustible resources, productive systems and ecosystems. Increasing resilience and opportunity within and between generations.
2. Maintaining consumption constant over time (and therefore maintaining income) as a minimalist imperative for material well-being maintenance.
3. Controlling for consistent levels of substitutability in both physical and money-value substitutability for any instrument of wealth.
4. Guaranteeing intergenerational equity, ensuring consistency along the development path.
5. Fostering intragenerational equity, increasing inclusiveness of institutions and promoting opportunity within generations.

Those five dimensions should be controlled for when assessing sustainability. They allow for a characterisation of sustainability in both states and paths and should be used as basis for sustainability indicators. Both current and present value indicators of sustainability should be designed taking one of those dimensions into account at least. Measures of comprehensive wealth and Adjusted Net Savings (ANS) are grounded in the neoclassical theory of value. They provide a first indication regarding criteria 1,2 and 4. As an all-encompassing indicator of long-run sustainability, ANS need to be completed by tests regarding substitutability and assessments of intragenerational equity. Following the logic of subsidiarity, those long run indicators should be completed by indicators with reduced scope in time and space.

Those “forward indicators” would be useful notably to assess the impact of the business cycle on sustainability, or regional level variables on national level. This distinction is not the distinction between present and current value indicators. Both kinds of indicators can be used at any scale, depending on relevance. Subsidiarity is very important here to avoid both the trap of missing a short term variable with long run cumulative effect and the trap of focusing on the long run while forgetting about current issues. Adopting this “dashboard” (Musson 2013) strategy of forward guidance could also help to address the uncertainty issue. Dasgupta (2001) stresses the difference between the perfect society, the “good enough society” (agathotopia) and the dysfunctional society (kakatopia). Sustainability assessment requires the assessment of those best case and second best scenarios. The generalisation of those tools (as scenarios or

confidence intervals associated with mono-scenario studies) is a good starting point and should be encouraged.

With present indicators to monitor the present state of sustainability in both time and space, broader indicators for longer horizons and larger areas could be amended regularly to solve consistency issue and detect deviations from the long run path. Critically, using those present value indicators of sustainability will allow a differentiate treatment for instruments of wealth depending on scale and time horizon. Water needs to be managed consistently over long horizons and in every region, when a harvest can be a sustainable issue only in some areas and for short periods. Articulating in a consistent manner the challenges brought by space and time to resource allocation is the core of economics. Our conviction is that sustainability needs to add equity and power concerns to the list to produce a meaningful theory to support sustainable development.

Conclusion

In this chapter we presented a framework for sustainable development and sustainability analysis. The weak sustainability paradigm is slowly erected from the early works on the DHSS model (Dasgupta and Heal 1974, Solow 1974, Stiglitz 1974) to answer the Rawlsian critique regarding the lack of intragenerational equity in economics. A second source of opposition to neoclassical economics can be traced back to the Club of Rome report (Meadows et al. 1972) which raised concerns about absolute resources scarcity. From this early work and the theoretical thinking of Georgescu-Roegen (1971), emerged the strong sustainability paradigm, concerned with physical substitutability and the carrying capacity of the environment. Concerns regarding sustainability clearly relate to an ethical, philosophical postulate about the importance of equity and justice in society. In that sense, sustainability is necessarily inserted in sustainable development. Sustainability can be defined as sustainable management of the means, when sustainable development link those sustainably managed means to the socially defined ends of development.

Assessing sustainability requires current value indicators, as sustainability has a temporal dimension. Sustainability is defined by a succession of states with suitable characteristics, forming a path that should be not only optimal but sustainable. In section I.2 we presented Adjusted Net Savings (ANS) which from the early works of Pearce and Atkinson (1993) grew to become the main current value indicator of sustainability. This single indicator provides a full characterisation of a development path. As we will see in chapter 4, it also provides a fair picture of the sustainability of development. Still, sustainability being one dimension of sustainable development, other elements need to be taken into account to characterise a sustainable development. In section II.1 we review the key role of institutions for sustainable development and their instrumental value for sustainability. We then show how the inherent uncertainty of the future and the need to assess the means and ends of development separately make the case for a coherent strategy for sustainable development, based on subsidiarity and the use of several indicators.

In the final part of the chapter we presented an integrated framework for sustainable development and sustainability. We conclude that sustainability can be reached by action on five dimensions: maintaining comprehensive wealth over time, maintaining constant consumption over time, controlling for money-value substitutability to be consistent with physical substitutability, guaranteeing intergenerational equity and fostering intragenerational equity. Coupled with the subsidiarity principle, those criteria should be assessed by current and present value sustainability indicators at different geographical scales. Current value indicators should be tested in scenarios to reduce uncertainty and maintain consistency in sustainable paths,

following the precautionary principle. ANS are ideally suited to perform this task of path monitoring, as counterfactual studies can be built in a theoretically consistent fashion using this indicator (see chapter 4).

Armed with this framework, we can now assess the consequences of international trade for sustainability. In the next chapter we review the existing literature on sustainability and international trade. We then propose an open-economy version of the framework presented in this chapter. Our aim is to focus on sustainability, the means of sustainable development. We will therefore not come back to the discussion over the goals of sustainable development. Nevertheless, further remarks on the instrumental role of institutions are provided in chapter 4.

CHAPTER 2

International trade and sustainability: exploring the linkages

1. This part is co-published with Matthew Agarwala in the second edition of the *Handbook of sustainable development* (forthcoming). I would like to thank him again for his patience with my often muddled thinking and his help and advice in setting up the presentation of the chapter in the Handbook, from which the current presentation heavily draws. Comments and suggestions from Giles Atkinson and Eric Neumayer are also gratefully acknowledged.

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Introduction

WE presented in the previous chapter the current state of the literature on sustainability. We concluded this presentation with a definition of sustainable development and sustainability. This definition led to the five dimensions of sustainability assessment. We highlighted the importance of consistency in scale and space when assessing sustainability, mostly by applying the subsidiarity principle. Current value indicators are better able to assess sustainability issues, but they need to be completed by medium scope indicators to assess the impact of medium to short run variables on sustainability. Finally, we stressed the role of intragenerational equity in minimising the consequences of uncertainty and the need for redistribution to maintain institutional sustainability. With those elements in mind, it is now time to turn to the second term in the dialectic of this thesis, namely international trade.

We would like to make a methodological point first. There is a great diversity of sources on the topic of international trade in a sustainability context. As in the first chapter, our aim is not only to undertake a review of the relevant contributions to our topic. As a consequence, in this chapter we conduct an exercise in classifying contributions using the definition of sustainability from chapter 1 as our guide. We believe the ever increasing number of contributions to the topic makes it impossible to provide a comprehensive assessment of the links between trade and sustainability without first conducting this classification work.

It is interesting to note there is no “sustainability study of international trade” or “theory of international trade and sustainability” as such. This does not mean that international trade has not been studied in the literature on sustainability. Nonetheless, the current state of the literature does not include a comprehensive analysis of the interactions between the study of sustainability and international trade. The study of international trade linked to sustainability issues is split between at least three fields: trade and the environment, open economy sustainability in resource economics and empirical sustainability. This absence of unity in itself is a motivation for this chapter. We would like to offer a potential reason for this absence. International trade has been used in sustainability studies mostly for specific questions: the resource curse, the pollution haven hypothesis, etc. The method of investigation involved building up on trade theory conclusions to complete the findings of closed economy sustainability studies. This led to skilful and elegant borrowing on both sides, but apart from the [Copeland and Taylor \(1994\)](#) model, no real synthesis.

Another potential explanation is methodological. Classical trade models are mostly based on comparative statics when sustainability is in essence a dynamic notion. The marriage of trade and sustainability therefore starts with the methodological difficulty of either studying

sustainability in a two-periods model or estimating dynamic patterns of trade. The first solution is of limited interest and the second might not yield original enough conclusions to justify the effort. Cross-fertilisation is much more frequent between macroeconomics and sustainability, were the tools are quite similar. A final potential reason is that sustainability study is relatively recent and not yet unified, with field specific questions such as pollution, climate change, etc. Building a theory of sustainability and trade is therefore first building a “unified” theory of sustainability, starting with a potential synthesis between weak and strong sustainability.

The literature on trade and the environment should not be confused with the emerging literature on trade and sustainability. The models in the trade and the environment literature are concerned with either the impact of trade on the management of a renewable resource (mostly fisheries and forests), or the impact of trade on the management of the assimilative capacity of pollutants as set by regulation. Those are important issues but the impact of trade on sustainability is more comprehensive, especially across time. In this chapter, we will first present several contributions to the understanding of the relationship between trade and sustainability. We then assess the impact of trade on the conclusions reached in chapter 1. In that sense, our aim is indeed larger than in most contributions in the trade and the environment literature.²

There are several reasons why the effort to build a “theory of international trade and sustainability” should be undertaken. A first reason is the emphasis put on export-led growth by the expansion of developing economies in Asia. This resulted in tensions on natural resources stocks worldwide. In the context of globalisation, sustainability is still mainly a national responsibility, even for issues such as global warming (after the failure to ratify international treaties). In the predominating view, trade is just a technical, welfare improving link between countries. The economics of the global supply chain are different, balancing international gains from specialisation with national gains from agglomeration and diversification. The debate over the pollution haven hypothesis (see section I) illustrates those contradictory forces at play. Studying the re-composition incentives of the global supply chain is therefore key to understand the potential impact of trade on sustainability. This motive could be related to the “space” dimension in figure 1.10 (see section III).

The second motivation is related to the “time” dimension. Beyond the methodological issue raised *supra* regarding dynamic trade models, the key question is the consistency between long run and short run imperatives. Nothing illustrates this better than the nature of development. In endowments terms, development is characterised by an increase in produced and human capital and by a reduction of the intensity of natural capital use. This transformation is

2. An interesting survey with a similar aim can be found in De Melo (2012).

usually termed structural change (López et al. 2007) and demands an evolution in the trade specialisation of the domestic economy, a move upmarket. When should a country abandon its static comparative advantage? Is the process driven by market forces, policy intervention? When and how should the shift occur?

This debate is far from over with Collier (2013) arguing for a focus on swift structural change and Yi-fu Lin (2012) insisting on strengthening comparative advantages first. Views on this point seem to depend on the time horizon adopted by the author. Still, as argued in section II.2, short-to-medium term decisions shape long run outcomes. It seems therefore impossible to settle for the absorption of trade impacts into a productivity term (Hartwick 1995), which is a perfectly sensible assumption in the long run but a poor policy guide on shorter horizons. The gains from trade are short term compared to the usual horizon of sustainability issues, but the economic structures under which they are obtained is relevant to sustainability.

The existing literature focus on more immediate questions and therefore use ad-hoc models to answer them. The most sustained effort to build a comprehensive theoretical framework is the Copeland and Taylor (1994) model, presented in section I. Built on the Heckscher-Ohlin (HO) model of international trade it helps to predict the overall impact of trade on the environment. The model is used to investigate the environmental Kuznets curve (EKC) and the pollution haven hypothesis (PHH), although the later treatment is completed by economic geography models. The Copeland and Taylor model is based on the HO assumption that factor endowments are the determinants of trade. It focuses on predicting the likely split of factor usage in the context of HO trade patterns.

A second important corpus in the literature focuses on the consequences of opening up a previously closed economy in terms of natural resources management. This literature is presented in section II under the label “open economy sustainability”. The conclusion of those models is that international trade is mostly a utility improving mechanism in the neoclassical tradition. It generates Ricardian-like productivity gains in countries engaging in international trade, shifting from a domestic price system to the system of world prices for natural resources. Interestingly, in both open economy sustainability and trade and the environment models, the assimilative capacity of the environment is considered to be a stock depleted by inputs of pollution.

Finally there is an important empirical literature focusing on the property of natural resources and responsibility for depletion. This literature burgeoned with the establishment of all-encompassing green accounting systems such as the SEEA.³ These authors focus on the

3. See <http://unstats.un.org/unsd/envaccounting/seea.asp>.

establishment of counterfactual scenarios as a way to evaluate the weight of resources in wealth and the likely outcome of natural resources policy. From this field emerged recently the concept of “virtual sustainability”, representing the difference between sustainability from production and actual sustainability linked to the final consumption of resources.

The weak versus strong sustainability debate imprinted the study of trade and sustainability. Trade being presented as a productivity and welfare improving mechanism in the neoclassical tradition, it is regarded with deep scepticism by ecological economists and proponents of strong sustainability, who consider it to be yet another element of the neoclassical economics they reject. In ecological economics, the perspective on the links between trade and sustainability is quite different. [Daly \(1992\)](#) pointed at the factor mobility argument (some also pointed at other fragile assumptions such as the factor price equalisation hypothesis), while [Rees \(2006\)](#) stressed the sociological consequences of trade. A tendency towards autarkic solutions predominates, for the sake of ecosystem managements and protection at the local level.

Whether to welcome or to criticise it, the different contributions to the literature find a significant impact of trade on sustainability. This impact is efficiently summarised in the Copeland and Taylor model under three effects: composition, technique and scale. Openness also creates the possibility to benefit from terms of trade variations in resources prices, which impact the valuation of domestic natural capital. As a result, sustainability on a development path is hard evaluate (let alone predict) because of those prices fluctuations. Openness to trade creates the possibility to invest the rent from resources in other countries, either to get better returns or for security reasons. Trade can also be a way to “cherry-pick” the less environmentally damaging elements of a production process while outsourcing the others. In the way it might improve overall production efficiency and reduce global pollution. The terms of the debate on trade and sustainability echo the debate on the social consequences of globalisation. Neoclassical models of trade yield the same contrasting picture of overall improvement, with the possibility of local losers. Mitigation of potentially harmful consequences of trade needs global coordination. We discuss in the final section the state of sustainability issues in trade policy.

As we saw in the previous section, the weak sustainability paradigm finds its expression in ANS and the Hartwick rule. Faced with the potential impact of international trade, [Hamilton and Clemens \(1999\)](#) propose an amendment to Adjusted Net Savings (see section II.2) to include net foreign assets holdings. Although significant, this amendment addresses only partially the original critique of Daly regarding factor mobility. Here are at stake the global trends, processes and interactions between countries. The study of international trade in sustainability has largely followed the principle of international trade as given (the open economy perspective).

This principle made sense for studies focusing on the impact of economic variables determined under international trade but only marginally (if at all) influenced by the domestic economy (such as natural resources prices).

Our objective here is to explore the relationship between trade and sustainable development, which is to be distinguished from the trade and the environment literature. Although some overlap is inevitable, this part is written from a sustainable development perspective, and requires the combination of theory from three sources: international trade, resource economics, and empirical sustainability. Analysis of the links between trade and sustainability naturally draws from international trade theory (Copeland and Taylor 1994, 2003, Grossman and Krueger 1991). But another important part of the literature, most closely associated with resource economics, investigates the links between trade openness and resource depletion (Hartwick 1977, Dixit et al. 1980, Asheim 1986, Asheim et al. 2003). We also draw from this tradition.

It is easily conceivable that trade directly affects sustainability through natural resources exchanges, but important indirect impacts derive from further consequences of trade liberalisation. Hence, we argue that trade policy should be assessed in the light of the impact on sustainability and sustainable development strategies. Although efforts have been made to present the theoretical impacts of international trade on sustainability, most of the recent work has been empirical (Atkinson and Hamilton 2002, Proops et al. 1999). The literature flourished in the analysis of the environmental Kuznets curve (EKC), the pollution haven hypothesis (PHH), and the resource curse (Dinda 2004, Grossman and Krueger 1991, Van Der Ploeg 2011). Many attempt to quantify the impact of international trade on sustainability through partial or general equilibrium analysis (Bailey and Clarke 2000, Turner et al. 2011) and amend sustainability indicators (Hamilton and Clemens 1999). This chapter also reviews those efforts.

Hence, in section I we present the literature on trade and the environment. In section II we focus on open economy resource economics and empirical sustainability. We then discuss the impact of the timing of trade liberalisation and the potential usefulness of trade management instruments. Finally, in section III we assess the impact of those contributions on the conceptual framework for sustainability presented in chapter 1 section II.3 and offer new fields of investigation to expand the knowledge on trade and sustainability.

I Trade and the environment

International trade is explained since [Smith \(1776\)](#) and [Ricardo \(1817\)](#) using the logic of comparative advantage. A comparative advantage is an advantage in production derived from several sources, creating an incentive to specialise. A country following its comparative advantages can expect income gains from international trade. The first model in [Smith \(1776\)](#) presents absolute comparative advantages. An absolute comparative advantage exists when a country can produce more efficiently than any of its partners a given good. All countries in this situation should specialise in that one good. The limit to this situation appears when one country is less efficient than all its potential partners in the production of every good.

In this case [Ricardo \(1817\)](#) shows that even a relative comparative advantage should induce specialisation. The more efficient partner should specialise in its strongest advantage and leave its least strong positions to the less efficient country. The Ricardian motive for trade is based on overall productivity in the production process. Differences in productivity between countries are the source of comparative advantage as factors are assumed to be homogeneous and immobile across countries. The Ricardian theory was formulated in terms of labour value and would be reformulated using marginal utility by [Haberler \(1930\)](#). [Deardorff \(1980\)](#) provides the modern general equilibrium formulation. The extent of specialisation in the case of a continuum of goods is debated in [Dornbusch et al. \(1977\)](#) and in a probabilistic setting in [Eaton and Kortum \(2002\)](#) and [Costinot \(2009\)](#).

Productivity differences are not the only source of comparative advantages. [Berthil Ohlin \(1933\)](#) and [Eli Heckscher](#) explained the patterns of trade by the relative factor endowments of the exchanging partners. Their framework of analysis is based on the 2 countries, 2 factors and 2 goods case. Despite the simplicity and illustrative power of this basic Heckscher-Ohlin (HO) theory, a rigorous analysis of factor content in international trade requires greater dimensionality than permitted by the 2-2-2 framework ([Leontief 1953](#)). The Heckscher-Ohlin-Vanek ([Harkness 1978](#), [Vanek 1968](#)) extends the H-O model to the n-goods case. The empirical validity of the model is still debated, although the most recent attempts using country-specific technology matrices are encouraging ([Burstein and Vogel 2011](#), [Leamer 1984](#), [Trefler 1993, 1995](#)). A review of HO models and results is available in [Baldwin \(2008\)](#).

Although clear and intuitive, the HO motive for trade fails to explain the development of intra-industry trade ([Grubel and Lloyd 1975](#)) after the second world war. The idea that countries could trade broadly similar goods could not be accommodated by the HO framework and the standard definition of preferences. The development of monopolistic competition and the Dixit-Stiglitz preferences ([Dixit and Stiglitz 1977](#), [Lancaster 1980](#)) opened the way to models

of intra-industry trade based on national (Krugman 1980, 1981) and international economies of scale (Ethier 1982). More will be said on intra-industry trade in chapter 4. The intuition in Krugman (1980) about the prominent role of agglomeration forces in the wake of increasing returns to scale in production reinstated geography in trade with the seminal contribution of Krugman (1991).

Those are the three main theoretical and empirical fields in international trade. Several sources of comparative advantages have been identified throughout the decades:

- differences in productivity
- differences in factor endowments
- gains from the international division of labour
- advantages arising from the taste for variety
- advantages from differences in regulation
- advantages from the relative distribution of firms size

Exploiting comparative advantages have an impact on resources allocation patterns, productivity, maximum consumption attainable, etc. On the basis of those comparative advantages, environmental economists tried to predict the impact of trade liberalisation on the environment (Baumol and Oates 1988). The first subsection below is dedicated to the presentation of the theoretical models on trade and the environment. The second subsection details empirical results. We notably insist on the roots and relative validation of the two main hypothesis in the literature: the pollution haven hypothesis (PHH) and the factor endowment hypothesis (FEH).

I.1 The Theory

Sustainability issues are usually framed in a dynamic model, due to the intergenerational dimension of the problem. In the natural resources context, the sustainability literature describes how much of a natural resource should be used at any point in time, and how it should be used (Hartwick 1977). The question answered by the trade and the environment literature is somewhat different. It emerged from the growing concern surrounding the notion of pollution. Pollution is assimilated to the degradation of the environment, the man-made alteration of an ecosystem, usually with both health and environmental consequences. Dealing with pollution required the implementation of gradually more stringent environmental norms.

Those norms tackle mostly pollution *emissions* from production and consumption. Reducing CO2 emissions or rain acidity through regulation of fume filtering at factories reduces produc-

tion emissions. Designing cars so that exhaust fumes are filtered from heavy metals reduces consumption emissions. The final aim of norms regarding emissions is to reduce *concentrations* of pollutants. Atmospheric pollutants are chemical components available in the atmosphere at concentration levels superior to a given level. Those sustainable levels of concentration are defined according to two criteria:

- The toxicity of those concentrations for human-beings.
- The assimilative capacity of an ecosystem, represented by the amount of dissipation physically possible.

A given chemical component can be more destabilising for human health than for the environment and vice versa. A similar logic can be applied to water pollution. Toxic concentration of a given pollutant can rapidly destroy ecosystems by making critical wildlife presence unsustainable. It can then harm the human population directly because of the toxicity from concentration, or indirectly by destroying human life-support functions in the ecosystem.

Environmental economics aimed at devising economic mechanisms (mostly incentives) to reduce pollution and to preserve ecosystem services that are by definition valuable for human-beings. This usually implies a trade-off between economic efficiency and environmental preservation. Before environmental norms, pollution was not valued, as the epitome of production externalities. In a closed economy settings, it makes perfect sense to arbitrage in favour of environmental preservation, as the “internalisation” of this externality would improve overall economic efficiency (Baumol and Oates 1988). The polluter would finally bear the true cost of production. Hanley et al. (2001) present how valuation of environmental benefits and costs improves decision-making, especially in infrastructure projects. Internalising externalities usually requires agreement upon market mechanisms to transfer rights or compensations between polluters and pollutees.

The question is more complex for an open economy. If discrepancies in environmental policy exist between two trading countries, the one favouring the environment is at a potential comparative disadvantage. Producers in the less regulated countries do not pay the full cost of production. This objection was raised in the United States during the negotiations leading to the North American Free Trade Agreement (NAFTA) at the beginning of the 1990’s. As the Mexican environmental legislation (and enforcement) was weaker, voices in the industry and environmentalist movements claimed the free trade agreement would result in sub-optimal outsourcing and regulatory “race to the bottom”. Confronted with unfair competition, there could also be strong lobbying against US regulation and pressure to water it down.

To address this concern, a technique to integrate pollution in a general equilibrium setting

was needed. Pollution is typically a by-product of the production process, an undesirable output. This feature makes it less tractable in a traditional setting where the output in its entirety should be maximised. It is however possible to consider pollution as an input in the production process. Pollution can be assimilated to the use of some of the stock of assimilative capacity in the environment, whether it be atmospheric degradation or water filtration. The assimilative capacity is the amount of a given component an ecosystem can tolerate before irremediable degradation of its functions. There is an amount of natural dissipation of pollutants, which can make optimal pollution management similar to other renewable resources. Formally, the inter-temporal optimisation problem can be formulated as:

Max:

$$\int_0^{\infty} [B(E_t) - D(Z_t)] \exp^{-rt} dt \quad (2.1)$$

$$(2.2)$$

Subject to:

$$\frac{dZ_t}{dt} = E_t - \delta A_t \quad (2.3)$$

$$Z_t = A(0) \quad (2.4)$$

$$Z_t \geq 0 \quad (2.5)$$

Where E is the level of emissions and B the benefits from it (in terms of output), D the cost function and Z pollution concentration. δ is the rate of natural decay in the atmosphere, with absorption capacity A . r is the rate of interest. The steady state first order conditions are:

$$\frac{\partial B}{\partial E} = \frac{\frac{\partial D}{\partial Z}}{r - \delta} \quad (2.6)$$

$$\delta Z = E \quad (2.7)$$

At the steady state, the extra benefit granted by an extra unit of emission must be equal to the extra cost from pollution, weighted by the interest rate net of decay. The value of emissions is equal to the value of concentration minus natural decay. Hence, from an economic perspective, the assimilative capacity should be optimally used, the “right amount” of pollution should be tolerated neither more nor less (Hanley et al. 2001). This optimal amount depends on physical parameters (the natural rate of decay and the damage function) and economic values (the rate of interest and the benefit function). The optimal level of emissions determined in this manner

can then be integrated into standard economic calculus. Consider a sector where good x and pollution z form the joint output (Copeland and Taylor 2003). The joint production functions are:

$$x = (1 - \Theta)F(K_x, L_x) \quad (2.8)$$

$$z = \varphi(\Theta)F(K_x, L_x) \quad (2.9)$$

Where Θ represents the allocation of resources between production of good x and abatement of pollution z . If there is no abatement ($\Theta = 0$), then each unit of output w produces one unit of pollution. Under the specific form $\varphi(\Theta) = (1 - \Theta)^{\frac{1}{\alpha}}$, substituting 2.8 into 2.9 gives to following production function:

$$x = z^\alpha [F(K_x, L_x)]^{1-\alpha} \quad (2.10)$$

Where pollution, labour and capital are the inputs in the sector. The demonstration holds for any functional form for F and φ that are linearly homogenous. It does not hold for functions exhibiting increasing returns to scale. It is therefore equivalent to consider pollution as an input in the production process or a by-product. This assumption gave birth to the use of tradable permits to give value to pollution. The right to deplete part of the assimilative capacity of the environment resides in the permit. Markets for those permits have been used locally and more ambitiously to reduce global CO_2 emissions (see for example Dijkstra et al. (2011)).

Using this technique, it is possible to introduce pollution in standard trade models. A 2-2-2 version of the Heckscher-Ohlin model has been adapted by Grossman and Helpman (1991), Grossman and Krueger (1995) to fit the analysis of the potential environmental consequences of the NAFTA⁴. They find that three effects of trade on the environment are at play, and the combination of those effects will determine the actual impact. Those effects are:

Scale effect: As an economy grows, emissions rise through a simple quantitative effect.

Technique effect: When the income of an economy increases, productivity gains and the larger share of resources available for pollution abatement reduce the overall level of pollution emissions.

Composition effect: Demand for environmental quality rises with living standards as a result of (trade induced) economic growth. Higher demand for the clean good results in a relative increase in the clean good sector size, lowering overall production pollution in the economy.

4. For North American Free Trade Agreement, a free trade agreement between Canada, Mexico and the US.

Those effects are computed assuming pollution concentration and emissions are internalised either via a tax, emission norms or tradeable permits. The nature of the composition effect changes if environmental policy is exogenous.

The Environmental Kuznets Curve (EKC) is derived from the three effects. The Kuznets curve is a U-shaped empirical relationship between inequality and GDP per capita. The EKC is also a U-shaped relationship, between pollution emissions and GDP per capita. The EKC is based on the three effects. As GDP per capita increases, pollution emissions will first increase as economic activity expands. Then, after a given peak, mounting pressure from citizens concerned with the environment will lead to more stringent environmental regulation. This should prop up innovation and bring down emissions. The economy will also have a tendency to produce higher-value goods, using more produced capital and becoming relatively less intensive in pollution. The combination of the technique and composition effect explain the downside of the curve. This approach was formally described in Copeland and Taylor (1994) and Copeland and Taylor (2003). In the third chapter of their book, Copeland and Taylor (2003) present the theoretical foundation of the EKC based on the threshold and income effect. They also examine the validity of increasing returns to scale in abatement. As abatement becomes more productive, firm allocate more resources to it.⁵

Copeland and Taylor (2003) propose a trade model with endogenous environmental policy, where better-off consumers lobby the government for more stringent environmental regulation. The government taxes pollution, so that increasing production brings both rewards (profits from increased sales) and costs (taxes from the increase in the pollution stock). The economy produces 2 goods, x and y , x generating pollution. y is the *numéraire* ($p_y = 1$). Two factors are used in the production process to start with, K and L , which supply is exogenous. Returns for K and L are r and w respectively. x is capital intensive and y is labour intensive:

$$\frac{K_x}{L_x} \geq \frac{K_y}{L_y} \quad (2.11)$$

There are two countries. The North is capital intensive and specialises in x , the South labour intensive and specialises in y . Both goods are produced using constant returns to scale technology. The production functions are:

$$y = H(K_y, L_y) \quad (2.12)$$

$$x = (1 - \Theta)F(K_x, L_x)z = \varphi(\Theta)F(K_x, L_x) \quad (2.13)$$

F is increasing, concave and linearly homogeneous. The firm splits inputs between abatement

5. Considering the somewhat disappointing results of empirical tests for the EKC, we won't present the extensions of the Copeland and Taylor model here. For empirical results, see section I.2.

to reduce emissions Z and production of good X . As $F(K_x, L_x)$ is potential output without abatement ($\Theta = 0$) then $x = z = F(K_x, L_x)$. Abatement creates the difference between potential and net output. Using the transformation described above, the production system reduces to equations 2.12 and 2.10. Once the abatement function is defined, firms will minimise the cost of production depending on capital, labour prices and abatement costs in sector x and only labour and capital in sector y . Equilibrium prices for labour and capital can be obtained subject to optimal abatement set by either taxation or tradeable permits. In this setting, the standard Stolper-Samuelson and Heckscher-Ohlin theorems hold. The Rybczinski theorem holds for a given level of emission intensity. Under the separability assumption, in an HO type setting factor prices are independent of endowments. The adjustment is made via output and therefore emissions. Pure scale and technique effects have straightforward implications: a more stringent regulation of emissions will *ceteris paribus* reduce the emissions, while a multiplication by a given factor of the size of the economy will increase them.

As the Rybczinski theorem holds, it is possible to obtain the net impact of capital accumulation on pollution and the impact of the composition effect. The impact of capital accumulation can be assessed via the three effects:

$$\frac{dz}{dK} = \frac{dx}{dK} + \frac{dy}{dK} + \frac{d(\frac{x}{S})}{dK} + \frac{de}{e} \quad (2.14)$$

The impact of capital accumulation on pollution can be decomposed into the variation of goods output divided by the scale S of the economy (scale), the impact of the increased output of x relative total output scaled by pollution intensity (composition) and the evolution in pollution intensity of production (technique). The impact of capital accumulation on pollution is positive: more capital abundant countries will pollute more. It should be noted this also implies an increase in labour endowment will reduce pollution emissions. This result flows naturally from the Rybczinski theorem.

The Copeland and Taylor model can be used to assess the impact of trade liberalisation on the environment, the potential formation of a pollution haven and the impact of factor accumulation on emissions. A question arises very quickly when the consequences of the three effects are clear. Under the composition and scale effects, countries relatively well endowed in produced capital (the North) should produce the “dirty”⁶ good x , and increase the production more than proportionally as capital is accumulated (Rybczinski theorem). In the meantime, those countries face growing pressure from a better-off population with a strong preference for environmental quality. Produced capital-intensive goods can then still be made in the North but with reduced emissions (technique effect) because of the more stringent environmental

6. Pollution intensive, that is.

policy. Alternatively, they could be outsourced in the South where regulation is less stringent.

This conclusion leaves the North and the South in an awkward position. The South have to arbitrage between industrialisation via emissions or environmental quality and continued poverty. The North should balance the demand for environmental regulation with the risk of de-industrialisation. To make things worse for the environment, it is quite common that property rights in the South are ill-defined. Some important natural resources are common access natural resources, subject to free riding and poaching. [Chichilnisky \(1994\)](#) shows that in this context inputs from the commons are supplied at sub-optimal prices relative to actual scarcity and subsistence labour. This leads the South to trade environmental quality for industrialisation at unfavourable terms. International trade in this setting results in over-exploitation of the commons and accelerated depletion. Similar observations lead ecological economists such as [Martinez-Alier \(1995\)](#) to observe that perspectives on the environment ought to be different in the North and the South. Southern countries are likely to consider the environment as an “unaffordable luxury”. Trade does not seem to make the conciliation of environmental preservation and economic development easier.

Those models are built on the Heckscher-Ohlin model and the criticism addressed to the HO approach is still valid. If factor price equalisation (FPE) breaks down either because of a non-traded good sector in the economy or because factor endowments are too diverse across countries, then the “canonical” theorems (HO, Stolper-Samuelson and Rybczynsky) no longer hold ([Deardorff 1994b](#)). Factor price equalisation is an essential assumption to prevent full specialisation in the clean or the dirty good. [Umanskaya and Barbier \(2008\)](#) consider an HO model where factor price equalisation does not occur. Factor prices may now differ and therefore relative factor prices matter more than relative endowments as prices are the variables of adjustment. The authors start from the 2003 Copeland and Taylor model, with abatement as in equation 2.10. In this setting, a country can specialise completely in the dirty good as long as the relative factor prices differential is wide enough. The North can specialise completely in the dirty good sector if the factor price differential is large enough compared to the regulation differential.

Empirical violations of the underlying assumptions of the HO models are one potential issue. Equally problematic is the fact that these models adopt a static⁷ framework, even though technical change and accumulation paths are obviously dynamic issues. The impact of dynamic structures will be detailed in chapter 3. We can nonetheless already mention that [Bogmans and Withagen \(2010\)](#) show how differences in the pure rate of time preference between

7. “We also worked within a static, perfectly competitive framework where [...] dynamic and strategic issues are entirely absent. This choice limited our methods and our results.” [Copeland and Taylor \(2003, p.280\)](#).

countries can result in the concentration of the dirty good production in the more impatient⁸ country.

Concentration of the capital intensive good production in the capital intensive country is a standard prediction incarnated in the Heckscher-Ohlin theorem. In the trade and the environment debate it is referred to as the factor endowment hypothesis (FEH). Verification of the FEH leads to the concentration of produced capital in the North and continuation of the usual North/South specialisation. Still, industries may want to avoid regulation in the North and take advantage of the large “assimilative capacity” available in the South. Southern countries have a strong incentive to use their low environmental regulation to attract produced capital and hasten development. This capital flight (in violation of the factor immobility assumption) is known as the pollution haven hypothesis (PHH).

Under this hypothesis the North specialises in the production of the clean good, as the price of emission increases. The South specialises in the production of the dirty good as the price of pollution is lower there. Under the PHH factor usage of capital decreases sharply in the North and increases in the South as a consequence of trade liberalisation. In this case, it is not so much outsourcing, but the opportunity cost that matters: investment that could have been made in the North is made in the South instead. The PHH, as the Stolper-Samuelson theorem before it, stresses that the global competition is as much between factors as it is between countries. Under free trade, even if overall pollution is reduced and gains from trade materialise, the South can be economically better-off and environmentally worse-off by welcoming pollution-intensive production processes.

The relative prevalence of FEH motives over PHH ones is in essence an empirical question (see section I.2). The other solution would be to study the dynamics of capital accumulation and the potential impact of other sources of comparative advantages. Industrial composition questions are fundamentally general equilibrium issues. In this scenario, the evolution of global environmental regulation and investment in produced capital in the North and the South should be endogenised. In the long run, as income increases, citizens in the South should start lobbying for stronger environmental regulation. In the meantime, as the South puts pressure on the remaining polluting industries in the North to outsource to the South, lobbying against environmental regulation in the North is likely to intensify. In this scenario, there is the real risk of a global race to the bottom in environmental standards.

Alternatively, one could consider that the gains from trade will bring environmental concerns in the front line so quickly that regulation will be tightened in the South before it is loosened in

8. Which is naturally the country with the highest pure rate of time preference.

the North. Expectations regarding this timing creates an opposition between “trade optimists” and “trade pessimists”. The FEH is based on the HO model, and translates into the Copeland and Taylor model. It is possible to modify the model to present the mechanisms behind the PHH. A first description is presented in Copeland and Taylor (2003), completed by empirical tests in Levinson and Taylor (2008). Starting with the same structure (see equation 2.8) the authors assume an exogenous pollution tax to regulate emissions. The North has a stricter pollution policy than the South, which results in higher emissions in the South ($e < e^*$ where e^* indicates the South). As p_y is the *numéraire*, the relevant world price is the price of x . The supply of x and y depends on those two factors, plus factor endowments:

$$x = x(p, e, K, L) \quad (2.15)$$

$$y = y(p, e, K, L) \quad (2.16)$$

See Copeland and Taylor (2003, p. 146). The expressions for the South are the same, emission intensity aside. The relative supply curve in each country of the dirty good x can be obtained as the ratio of expressions 2.15 and 2.16. As demand functions are the same across countries, if emissions intensity were similar, relative supply functions would be the same and there would be no trade. Lower emissions in the South make the relative price of x lower there, resulting in an increase in production of x in the South to export in the North. It should be noted that as emissions are capped, overall pollution is unchanged. Differences in regulation create the opportunity to trade and the formation of a pollution haven in the South. The authors present several other cases based on different motives for the difference in environmental regulation stringency. The difference can also arise from discrepancies in environmental resilience (the environment in one region can absorb more pollution) or asymmetries in income level. The overall impact of trade liberalisation in the context of discrepancies in environmental policies is always the concentration of the polluting industries but the overall impact on the environment is less clear. The formation of a pollution haven can be beneficial if it takes place in the country where the assimilative capacity is the strongest. The overall effect can be null if overall caps on emissions are in place and properly enforced.

Concentration of the dirty good production in one country suggests that agglomeration forces and increasing returns to scale have a critical impact on pollution haven formation. Intuitively, internal economies of scale would only magnify the results obtained under constant returns to scale. External economies of scale and the formation of true “pollution intensive Marshallian districts” could provide a powerful rationale for both the formation and persistence of pollution havens. A first contribution by Benarroch and Weder (2006) is based on a 2 countries setting with Dixit-Stiglitz monopolistic competition. Only trade in intermediate

goods take place while pollution comes from the use of pollution intensive intermediates. In this setting, pollution is lowered by economies of scale and trade tend to improve environmental quality in pollution intensive countries. [Zeng and Zhao \(2009\)](#) use a spatial model to explore pollution haven formation and also conclude that the addition of agglomeration forces can reduce the likelihood of a pollution haven formation. Theoretical results are therefore leaning on the “trade optimists” side.

Trade pessimists are numerous amongst ecological economists. After [Daly \(1992\)](#) they refute the conclusions of the Copeland and Taylor model, arguing that factor mobility greatly diminishes the value of Ricardian arguments. Proponents of strong sustainability often take a critical view of international trade: it exacerbates stress on ecosystems, disturbs local and global socio-ecological balances and may hasten the depletion of the critical natural capital. International trade analysis derives from neoclassical theory. The neoclassical misconceptions regarding the ability of the environment to withstand continuous growth are also present in international trade analysis. Moreover, international trade could export unsustainable development strategies to the South and exert erosive pressure on environmental regulation in the North ([Muradian and Martinez-Alier 2001](#), [Schneider et al. 2010](#)).

Proponents of strong sustainability are often concerned about transboundary pollution flows ([Maddison 2006, 2007](#)) although recent works within the weak sustainability paradigm also address this issue ([Arrow et al. 2010](#), [Atkinson et al. 2011, 2012](#)). Finally, because the place of extraction and final consumption may lie thousands of miles apart, international trade short-circuits traditional (local) feedback mechanisms that might provide advanced warning and prevent excessive environmental degradation. Natural resources trade implies that unsustainable regions can rely on sustainable regions’ resources, ultimately compromising sustainability everywhere ([Rees 2006](#)). This point will be discussed further in subsection II.2.

The Copeland and Taylor model proved to be a powerful tool to assess the impact of trade on the environment. The redefinition of pollution concentration and emissions issues into a factor endowment one (conditioned by environmental policy) allowed the treatment of a wide variety of cases. The model manages to support the treatment of both the factor endowment and the pollution haven hypothesis. The decomposition of trade impacts between the scale, composition and technique effect help to evaluate policy measures accurately. The model is nonetheless limited by the standard HO framework it rests on. The relation between factor usage and factor accumulation is only described in comparative statics, under the assumption of full employment.

As for the PHH, the latest work explicitly modelling agglomeration forces seem to do a better work at assessing concentration. Nonetheless, even under this different modelling strategy, the

risk of seeing pollution havens emerging is still low. When confronted with conflicting theoretical prediction, empirical validation is needed. The next section reviews the empirical evidence on the EKC, the FEH versus the PHH and estimates of trade-induced elasticities.

I.2 Empirical Evidence

Conclusions of the theoretical models in the trade and the environment literature demand empirical validation. The first empirical tests were conducted on the EKC to address the arguments of trade pessimists regarding environmental damage and growth. The literature is rich in plain empirical tests but also in tests based on the Copeland and Taylor model. Gradually, the interest in the field moved to tests regarding the pollution haven hypothesis and the relative size of the three effects. An interesting conclusion notably emerges from [Cole and Elliott \(2003a\)](#), who focus on trade-induced effects. They conclude that trade is generally not the main driver of negative environmental impacts, but acts as a magnifying force.

The biggest bone of contention in the literature was doubtlessly the EKC. As a straightforward relationship commanding applicable policy to protect the environment (favour fast growth), it could vindicate the trade optimists. The question of PHH versus FEH is critical in terms of policy. If FEH dominates, high environmental standards can survive globalisation. Conversely, if PHH dominates, a race to the bottom in environmental standards is most likely as the North will try to prevent capital flight to the South. The first test bringing evidence of the EKC was conducted by [Grossman and Helpman \(1991\)](#). Analysing trade between the US and Mexico, the authors use comparative statics to determine whether the composition and technique effects dominated the scale effect. If so, per capita GDP growth would reduce pollution. The authors use sulphur dioxide and dark matter *concentrations* as proxies for pollution stocks. They conclude that trade brings a net benefit to the environment, the turning point of the EKC being between 4000 and 5000 1985 USD.

Building on this first study, they seek evidence (and formalise the concept) of the EKC in a later contribution ([Grossman and Krueger 1995](#)). They test for a larger range of pollutants including in excess of the previously cited heavy particles. They also test for water pollution. The authors conclude that although turning points vary from one pollutant to another, in “most cases” they are reached before the country reaches a per capita income of 8000 1985 USD. From those early contributions, a very rich literature on the EKC followed. Comprehensive surveys include [Gallagher \(2008, Part 1\)](#), [Dinda \(2004\)](#) and [Kijima et al. \(2010\)](#). The econometric model varies depending on the number of controls, but the basic form is always the same:

$$y_{it} = \alpha_i + \beta_1 x_{it} + \beta_2 x_{it}^2 + \beta_3 x_{it}^3 + \beta_4 z_{it} + \epsilon_{it} \quad (2.17)$$

Where y is the indicator for environmental degradation (usually sulphur or CO_2 concentrations, and latter emissions), x is income and z represent the sets of controls (Dinda 2004). The EKC is characterised by $\beta_1 > 0$, $\beta_2 > 0$ and $\beta_3 = 0$. A first convincing case was brought by Hilton and Levinson (1998) using data from the automotive industry. Andreoni and Levinson (2001) build up on those results, testing for macro indicators such as institutions and the business cycle. Harbaugh et al. (2002) complete this first set of specification tests, controlling for lagged GDP and situational variables (city centre, residential area, etc.). This study compares the original Grossman and Krueger (1995) results with its revised dataset and finds a significant increase in the value of the peak in the bell. From 4000 USD it is now estimated to be 13741 USD when considered the original sample with extra controls and 20081 USD with the full size of the new dataset. The slopes are also far less steep, suggesting a slower build-up of concentration, but also a slower reduction after the peak.

Subsequent studies have enlarged the range of pollutants involved (Frankel and Rose 2005) and the nature of abatement costs (Managi et al. 2009). Maddison (2006) included tests for spatial spillovers, one country's emissions depending on its neighbours' policy. The emerging consensus in the literature is that the EKC might be misspecified (Kijima et al. 2010) or just a particular case in the relationship between income and the environment (Wang 2013). The relationship between GDP per capita and pollution is probably more complex. As some key variables in the relationship are missing, estimates find a tipping point in the conventional bell curve only the highest-income country can reach. Critics of the curve warned that the relation probably did not exist, first on strong sustainability and institutional grounds (Tisdell 2001), then on the basis of the need to take consumption of resources into account to gauge environmental quality (Mills Busa 2013). It seems safe to say that the EKC failed to be an all-encompassing empirical regularity in environmental economics (similar to gravity equations in trade analysis).

The Copeland and Taylor model is designed to present the links between the scale, technique and composition effects. Empirical tests of the model are based on observable variables (such as concentrations of pollutants) that varies in line with the predictions of the model. A first test provides estimates of the relative magnitudes of the pro-environment technique effect and the anti-environment scale effect. A second test investigates whether the composition effect leans towards the FEH (building up pollution in rich countries) or the PHH (building up pollution in poor countries). In Antweiler et al. (2001), the authors use equation 2.14 as the basis for

their test on the relative magnitude of the three effects. The model requires data on emissions levels, but only data on concentrations are available. To solve this problem, data from local measurement stations are used and scaled by city size, capital labour ratio and trade intensity. Stations become in this manner an approximation of local firms. As many relevant variables are unobservable, the authors decompose their fixed effects into three:

$$\epsilon_{ijkt} = \xi_t + \Phi_{ijk} + \nu_{ijkt} \quad (2.18)$$

The total fixed effect for station i in city j in country k in year t is a function of a time-specific effect ξ , a site-specific error Φ and an idiosyncratic measurement error ν . The econometric strategy allows for the joint testing of the three effects, in line with the theoretical predictions of the model. The results from [Antweiler et al. \(2001\)](#) are reproduced in table 2.1. The scale effect appears clearly with the significance of the variable GDP/km^2 across all models. The composition effect embodied in the Capital abundance (K/L) ratio is positive (increases emissions). This result is also, as the authors note, to the credit of the HO model and proves its validity at least at the aggregate level. Finally, the technique effect represented by the (lagged) per capita income is strongly negative across specifications. The results on the trade-induced composition effect are somewhat weaker, but indicate on average a negative relationship. The trade-induced composition effect reflects the reaction of the country to trade liberalisation, and should therefore be either positive or negative, depending on country factor endowments. Overall, the authors find trade to be good for the environment: the scale effect is dominated by the technique effect and the overall composition effect (trade induced and not) is negative. The conclusion also broadly supports the FEH against the PHH, as capital intensive countries retain their specialisation even as the technique effect marks down emissions.

The emphasis put on trade-induced effects as a part of plain effects was key to test the relative importance of the FEH against the PHH. Another important question was the validity of the results in [Antweiler et al. \(2001\)](#) with emissions instead of concentrations as the dependant variable. Finally, pollutants other than SO_2 matter for the environment: focusing on a single pollutant because of data availability also narrows the range of industries studied. [Cole and Elliott \(2003a\)](#) address those issues by assessing the composition effect using four pollutants as the dependent variable. They conclude that the composition effect is small relative to the other two and support the findings from [Antweiler et al. \(2001\)](#). The factor endowment effect is at best stronger than the pollution haven effect, at worst equal. Finally, they confirm that trade lowers the pollution intensity of output, but can not confirm unequivocally that trade liberalisation will lower overall pollutants as the result vary depending on the pollutant. The conclusion is enriched by a follow-up article which concludes that the differential in environmental regulation is likely to influence the share of inter-industry against intra-industry trade

Table 2.1: Testing the Copeland and Taylor model

Estimation method: Model specification: Variable/column:	Random effects			Fixed effects		
	A (1)	B (2)	C (3)	A (4)	B (5)	C (6)
Intercept	-2.865***	-3.279***	-3.311***	-2.506***	-4.324***	-4.299***
City economic intensity GDP/km ²	0.042***	0.058***	0.070***	0.024*	0.058***	0.089*
(City economic intensity) ² /1,000			-0.244			-0.340
Capital abundance (K/L)	0.102**	0.293**	0.286*	0.165**	0.461**	0.437*
(K/L) ²		0.014	0.013		0.006	0.008
Lagged per capita income	-0.982***	-1.248***	-1.312***	-1.326***	-0.096	-0.228
(Income) ²		0.708***	0.669***		0.559***	0.578***
(K/L) × (I)		-0.309***	-0.285***		-0.381***	-0.386***
Trade intensity TI = (X+M)/GDP	-0.915	-0.488	-0.510	-3.677***	-3.142**	-3.216**
TI × REL.K/L	-0.462	-1.952*	-1.828*	0.159	-2.252*	-2.121
TI × (REL.K/L) ²	0.018	-0.230	-0.248	-0.168	-0.123	-0.176
TI × REL.INC	0.470	1.056*	1.011*	2.128**	2.687***	2.614***
TI × (REL.INC) ²	0.118	-0.308*	-0.285*	-0.108	-0.595**	-0.584**
TI × (REL.K/L) × (REL.INC)	-0.165	0.870***	0.822***	-0.280	0.900**	0.924**
Suburban dummy	-0.299	-0.435*	-0.422*			
Rural dummy	-0.623	-0.674	-0.631			
Communist country (C.C.) dummy	0.312	-0.252	-0.257			
C.C. dummy × income	-0.283	4.569*	4.641*	1.170	9.621**	9.639**
C.C. dummy × (income) ²		-5.755**	-5.788**		-8.931***	-8.806**
Average temperature	-0.055***	-0.052***	-0.052***	-0.060*	-0.057*	-0.056*
Precipitation variation:	3.446	5.860	6.158	8.599	10.810*	10.716*
Helsinki Protocol:	-0.232*	-0.092	-0.114	-0.179	0.016	0.016
Observations	2,555	2,555	2,555	2,555	2,555	2,555
Groups	290	290	290	290	290	290
R ²	0.3395	0.3737	0.374	0.2483	0.131	0.1499
Log-likelihood	-2550	-2523	-2522	-3964	-3906	-3905
LR test/χ ² (df)	55.596***	1.604		118.42***	2.035	
Hausman test/Wald χ ² (df)	65.761**	15.158	53.789			
Scale elasticity	0.192***	0.265***	0.315***	0.112*	0.266***	0.398**
Composition elasticity	0.583**	0.948***	0.993***	0.945**	1.006**	0.975*
Technique elasticity	-0.905***	-1.577***	-1.577***	-1.222***	-1.153**	-1.266**
Trade intensity elasticity	-0.436***	-0.388***	-0.394***	-0.641***	-0.864***	-0.882***

Notes: To conserve space, no standard errors or *t*-statistics are shown. The dependent variable is the log of the median of SO₂ concentrations at each observation site. Model A follows directly from our empirical implementation, whereas model B allows for additional interaction between capital abundance and income. In addition to model B, model C allows for nonlinearity in our scale variable. All model specifications use time-fixed effects. Elasticities are evaluated at sample means using the Delta method.

* Significance at the 95-percent confidence level.

** Significance at the 99-percent confidence level.

*** Significance at the 99.9-percent confidence level.

Source: Antweiler et al. (2001)

in a trading relationship (Cole and Elliott 2003b).

Those early tests suggested that environmental regulations do not play an important role in shaping trade patterns. This result being at odds with anecdotal but persistent evidence, specific tests for the PHH were subsequently proposed. Cole (2004) linked the test of the PHH to the EKC, investigating whether the downward slopping part of the bell could be explained by industry migration to the South. Testing the EKC for several pollutants (NO_x , SO_2 , CO , SPM , VOC , CO_2) they add a variable for the weight of net pollution-intensive good exports relative to domestic consumption and find no evidence of durable pollution havens. More encouraging were the studies of Ederington et al. (2005) and Cole et al. (2010) which control for the nature of trade (North-South or South-South) and the industry. They find support for the PHH in South-South trade, and Cole et al. (2010) show that the effect gets stronger when environmental costs are high and geographical immobility (“footloose” industries) is taken into account. Kellenberg (2009) finds evidence for the PHH in the context of strategic environment and trade policy. Those results suggest that domestic agglomeration forces are especially strong in capital intensive industries, making them less sensitive to differential in environmental regulation. If those forces, while driving trade flows, can be controlled for, then pollution haven effects can be found for some industries and some countries. All in all, environmental regulations have a stronger impact on more mobile industries and sectors and mostly in South-South trade. Both PHH and FEH are at work to explain the trade/environment relationship, one being stronger than the other according to the level of development and the industrial specialisation (Kellenberg 2008). It should be borne in mind that the results are however sensitive to the pollutant used.

This concludes the section on the trade and the environment literature. After more than twenty years of modelling and testing, the potential impact of environmental regulation and pollution on trade flows seems in the end to be statistically significant but limited in size. When reaching this somewhat disappointing conclusion, it is useful to remember that trade flows themselves (goods and services) are not a large part of overall output. It is nonetheless surprising that beyond some renewable resources and trade-induced composition and technique effects, the impact of trade on the environment remains minimal. However, this literature is only one of the literature investigating the links between trade and sustainability. The impact of trade openness on domestic decisions and endowments may be a bigger contribution from trade than trade flows themselves. It is this literature, we define as the “open economy sustainability” literature, that we will now investigate.

II Open economy sustainability

In the previous section we reviewed the literature on trade and the environment, culminating in the tests regarding the pollution haven hypothesis against the factor endowment hypothesis. Those two hypothesis illustrated the possible divergence in trade impacts, depending on the theory used. They converged however in explaining some domestic sustainability issues (such as the EKC) with trade models. The literature on trade and the environment mostly deals with stock pollutants as a proxy for environmental quality, and to some extent with renewable resources. It analyses the impact of environmental factors on trade flows. The scope of empirical validation is limited by the data available, although this problem is getting less acute as environmental accounts develop. The literature we will now present takes a different perspective. It finds its source in resource economics, dealing mostly with valuable exhaustible resources. It is concerned with optimal planing of depletion and investment of natural resources in an open economy. The models in this literature consider national economies trying to address sustainability issues under the changing circumstances determined by world prices (as opposed to domestic) and a wider (worldly) array of investment opportunities for natural resources rents. From a conceptual perspective, the literature on trade and the environment focuses on producing a more sustainable *global* outlook. The current literature takes the implicit view that sustainability will be achieved country by country at the national level.

Weak sustainability has historically emphasised domestic management of instruments of wealth following the Hartwick Rule, as exemplified by the capital theoretic approach (Hartwick 1977, Neumayer 2010, Pearce and Atkinson 1993). A first object of inquiry is therefore the translation of closed economy sustainability rules to the open economy setting (Asheim 1986). A second important avenue of investigation tackles the impact of differences, now and in the future, between domestic and world prices (Hartwick 1995). Variations in world market resource prices introduce uncertainty in optimal depletion paths at the national level (Pezzey 2004). Those contributions need taken into account when estimating the empirical impact of international trade on sustainability and sustainability indicators (World Bank 2006). New perspectives on sustainability indicators could lead to a shift in the responsibility for depletion and therefore in the country by country sustainability outlook (Proops et al. 1999, Atkinson and Hamilton 2002).

II.1 Sustainability and Reinvestment in open economies

As presented in section I, the main sustainability model is the DHSS model. Under standard assumptions, optimal depletion paths for natural resources are a necessary condition for sustainable development. Empirical assessment of the DHSS model is usually conducted using the Hartwick (1977) rule, which actual meaning and scope have been debated long after its first formulation (Asheim et al. 2003). Some controversies over the rule remain, but the general message that a “sound” reinvestment policy for resource rents is a pre-requisite for sustainable development is now well-established. The original Hartwick rule is enunciated using a closed economy model. Opening up the economy leads to amendments to the rule, first presented by Asheim (1986) with subsequent extensions in Hartwick (1995) and Vincent et al. (1997). The Asheim (1986) argument lies on those very underlying assumptions regarding constant technology and population. Asheim shows that terms-of-trade variations for a price-taking open economy are equivalent to a violation of the constant technology assumption.

In a closed economy setting, the path for resources depletion as specified according to the Hotelling rule is perfectly defined. As the resource gets scarcer through depletion, the price increases. In an open economy setting, this price increase goes with a betterment of terms-of-trade, generating a proportional extra inflow of income. This is similar to productivity gains coming with resource extraction in the closed economy setting. The Hartwick rule should therefore be amended for this gain from the terms-of-trade effect, as it reduces the amount of reinvestment needed today. Future generations can rely on the windfall from the terms-of-trade effect, and be better-off with less physical resources. Hartwick (1995) builds on this conclusion to build a dynamic Solow (1974) model with two countries engaging in free trade. Countries exploit a resource $S(t)$ depleted of quantity $R(t)$ each period to produce $Q(t)$ with capital $K(t)$ and the standard function $F(K(t), R(t))$. $K(t)$ does not depreciate and $K(t)$ and $R(t)$ are perfectly substitutable. Population N is constant. The rule for investment is assumed to be:

$$\dot{K}(t) = \gamma(t)R(t)F_R(t) \quad (2.19)$$

With $F_R(t)$ the first derivative of F with respect to R . Under the Hotelling rule, following the Hartwick rule ($\gamma = 1$) yields constant consumption over time. From this one country setting, resources are split unequally between two price-taking countries, similarly endowed in

population and capital:

$$K_1(t) = K_2(t) \quad (2.20)$$

$$K_1(t) + K_2(t) = K(t) \quad (2.21)$$

$$N_1 = N_2 \quad (2.22)$$

$$N_1 + N_2 = N \quad (2.23)$$

$$S_1(t) < S_2(t) \quad (2.24)$$

$$S_1 + S_2 - 2 = S(t) \quad (2.25)$$

Country 1 imports $\epsilon(t)$ of resources from country 2 at each date. Since capital endowments and technology are similar, resource imports are used to balance resource endowments at every period. For country 1, consumption equals output minus investment and imports:

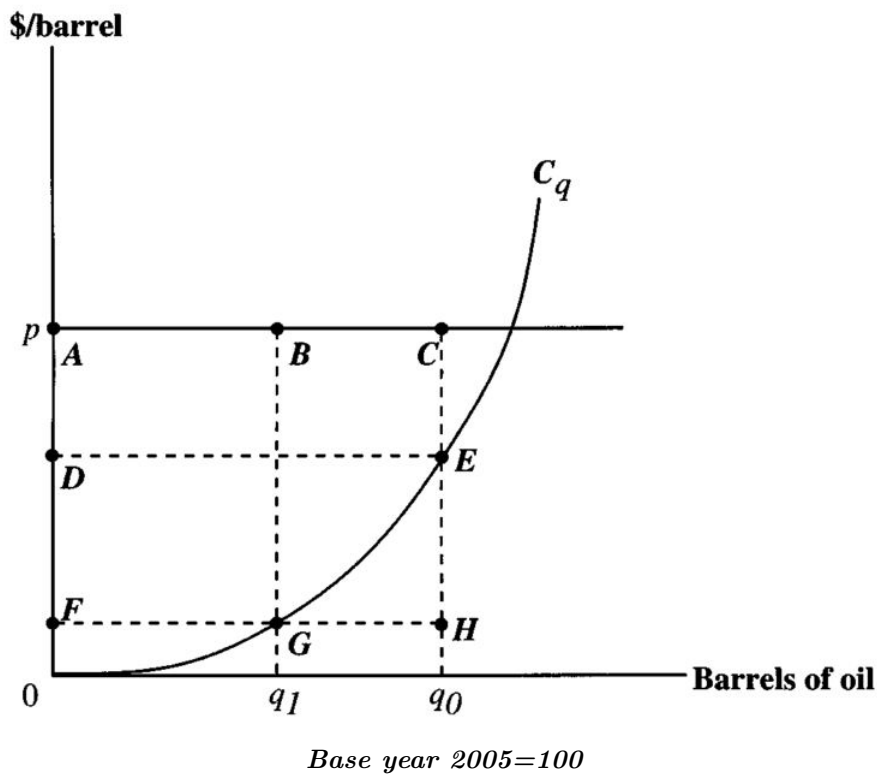
$$C_1(t) = F(K_1(t), R_1(t) + \epsilon(t)) - \dot{K}_1(t) - \epsilon F_{R1}(t) \quad (2.26)$$

The savings rule requires investment to cover for the depreciation of the resource stock, so country 1 covers the depletion of its own stock, minus the share of natural resources use that is imported. This adjustment is the key difference between the autarky and trading scenarios. Under this adjustment, the original savings rule ($\dot{C}_1 = 0$) requires:

$$\frac{(1 - \gamma_1(t))(R_1)}{\epsilon(t)} = F_K(t) \quad (2.27)$$

The rate of interest on capital is equal to the amount of resources extracted domestically minus the volume imported, discounted by the price of those imports. $\epsilon(t)\dot{F}_R(t)$ represents the terms-of-trade effect in natural resources trade: it should be subtracted from the level of constant consumption to pay for natural resources imports. Without the constraint of the constant savings rule, country 1 exhibits an interesting behaviour. In period 1 it pays the highest price for natural resources imports and “under-saves” to be able to pay. As substitution occurs over time, it slowly erodes the bill and the maximum attainable level of consumption converges toward the long run level of the autarky model. The situation in country 2 is the exact mirror. This result can be extended to the n country case as long as starting endowments in K are still equal. A full trade model should be used to make predictions if it were not the case. The conclusions of the model are therefore similar to [Asheim \(1986\)](#) although the nature of the adjustment (i.e the terms-of trade effect) is grounded in the trade pattern. The treatment of this issue was latter completed by [Vincent et al. \(1997\)](#) which characterised the size of the adjustment to the terms-of-trade effect as “capital gains” as they would ultimately be added to wealth through reinvestment. [Vincent et al. \(1997\)](#) also investigate further, with the empirical

Figure 2.1: Open economy resource management under exogenous prices



Source: Vincent et al. (1997)

example of Indonesia, the theoretical distinction between constant exogenous world prices⁹ and endogenously determined world prices.

The nature of world prices has an impact on the size of the terms-of-trade effect. They are endogenous in Asheim (1986), and both cases are examined in Hartwick (1995) and Vincent et al. (1997). If we take the perspective of resource exporters, endogenous prices systematically yield capital gains, raising questions regarding primary and secondary reinvestment. Exogenous prices prevent price adjustment in a dynamic setting, which is then performed by quantity adjustment. Quantities extracted diminish over time as the prices paid cannot increase¹⁰ (figure 2.1) but rents in excess of current consumption are invested abroad.

To maintain consumption constant over time, the optimal planner uses current non invested rents and interests on previous investments. Therefore, the turn back to the closed economy

9. A standard assumption in “small open economy” models.

10. The authors assume the Hotelling rule holds, so that marginal rents increase over time. It is therefore optimal to extract the resource as long as the marginal rent is in excess of the rate of interest, but only as long as the rent is non-negative. If the price is constant, quantities extracted must fall to maintain marginal and Hotelling rents.

setting is much quicker as quantities extracted shrink faster. Exogenous and endogenous world prices only make a difference in terms of size and duration of the capital gains. Conclusions regarding the capital gains are obtained in dynamic settings optimised over an infinite period. In chapter 1 section I.1 we observed how the literature treated the impact of time and uncertainty, assimilating the time going by as an investment in an instrument of wealth. The time horizon when assessing the impact of trade on sustainability is incorporated in a similar fashion.

We saw *supra* that when [Asheim \(1986\)](#) looked at the impact of opening-up economies on the Hartwick rule, he assimilated it to a productivity shock. This makes sense as for the domestic economy, the capital gains are similar to Hicks-neutral technical progress (the same amount for a higher selling price against the same amount for a lower buying price). This also makes sense from a methodological perspective as Hicks-neutral technical progress is easy to investigate in a [Solow \(1974\)](#) model. The impact of trade is then merged with other unobservable dimensions of development (such as efficiency gains from improvement in institutions) into a time-dependent variable. This strategy is adopted in several contributions ([Arrow et al. 2010](#), [Pezzey 2004](#), [Pezzey et al. 2006](#), [Rubio 2004](#)) where the passing of time is assimilated to investment into a productive stock. [Pemberton and Ulph \(2001\)](#) first formalised this intuition, based on the seminal model in [Weitzman \(1976\)](#).

The original aim of the [Weitzman \(1976\)](#) article was to investigate technical change. The author shows that if technical progress is exogenous, it is possible to preserve the welfare properties of comprehensive wealth indicators by introducing time dependence as investment in time in the optimal planning process. This reduces the problem of optimal planning with exogenous technical progress to optimal planning without technical progress with one extra form of capital to invest in. Formally:

$$(c_t, I_t, I_{(n+1)t}) \in \Upsilon \Leftrightarrow (c_t, I_t, K_t) \in F_t, K_{(n+1)t} = t \text{ and } I_{(n+1)t} = 1 \quad (2.28)$$

With c_t consumption in t , I_t investment in t , K_t the stock of capital in t , F_t the time dependent production set and Υ the time independent production set. This redefinition of the optimum is quite similar to the one undertaken by [Solow \(1974\)](#). A simple illustration of this can be found in [Arrow et al. \(2010\)](#):

$$W(t) = r(t) + \sum_{i=1}^n p_i(t) K_i(t) \quad (2.29)$$

Where $W(t)$ is comprehensive wealth¹¹ at time t , $p_i(t)$ the shadow price of asset i in time t ,

11. Comprehensive wealth is a dynamic analogue of real national income. See [Arrow et al. \(2010\)](#) for more details.

$K_i(t)$ the stock of asset i in t and $r(t)$ the shadow price of time in t . Pezzey (2004) uses this same technique to propose an assessment of Adjusted Net Savings (ANS) as a sustainability indicator with changes in technology, trade and pollution. The adjustment for trade, our source of concern here, is conducted on the basis of the exogeneity of world prices. The theoretical expression obtained for the overall time dependent gains (including trade, but also exogenous technical progress) is similar to the one in Hartwick (1995).¹² The “price of time” is evaluated using future prices, which can only be observable on forward markets under the hypothesis of market efficiency. This makes estimates of the price of time over an infinite horizon especially hard to compute.

Variations in world market prices and uncertainty over the size and timing of those variations are more problematic to estimate than capital gains. This amounts to a violation of the efficient market hypothesis. From a sustainability perspective, exogenous changes in natural resources prices command countries to invest (consume) the negative (positive) difference between Hotelling rents and the discounted sum of future terms of trade effects. The Simon and Erlich bet reminds us that scarcity and the implied raise in the Hotelling rent is dependent on global demand, exploration and technical progress. The treatment of capital gains in empirical estimates is rendered difficult by this uncertainty over the course of world resource prices. A country could calibrate reinvestment policy and reasonably expect a stable improvement in its terms-of-trade in line with increasing scarcity, to find itself confronted with abrupt phases of decreasing prices.

This makes the estimation of capital gains hard to perform, a fact acknowledged in Hartwick (1995). Whether or not this element of uncertainty should be considered is still debated on two grounds: it is notoriously hard to estimate and resources prices fluctuations may result in an evening out of the negative and positive capital gains. Hamilton and Clemens (1999) and Vincent et al. (1997) decided against including them, but Arrow et al. (2010) decided for doing so. This issue should be weighted according to the empirical importance of capital gains. Inclusion is also highly dependent on the time frame considered. In their study, Arrow et al. (2010) find the time dependent variable, measuring amongst other things the impact of trade, to account for more than 50% of the change in comprehensive wealth between 1995 and 2000 for the five countries¹³ investigated. Those recent results suggest that capital gains are important and that the impact of trade is likely to be more than marginal (see subsection II.2 below). Confronted with this potential magnitude, capital gains can hardly be neglected. Time dependence should be included if the components contributing to it cannot be measured.

12. See equation 23 in Pezzey (2004).

13. Brazil, China, India, The US and Venezuela.

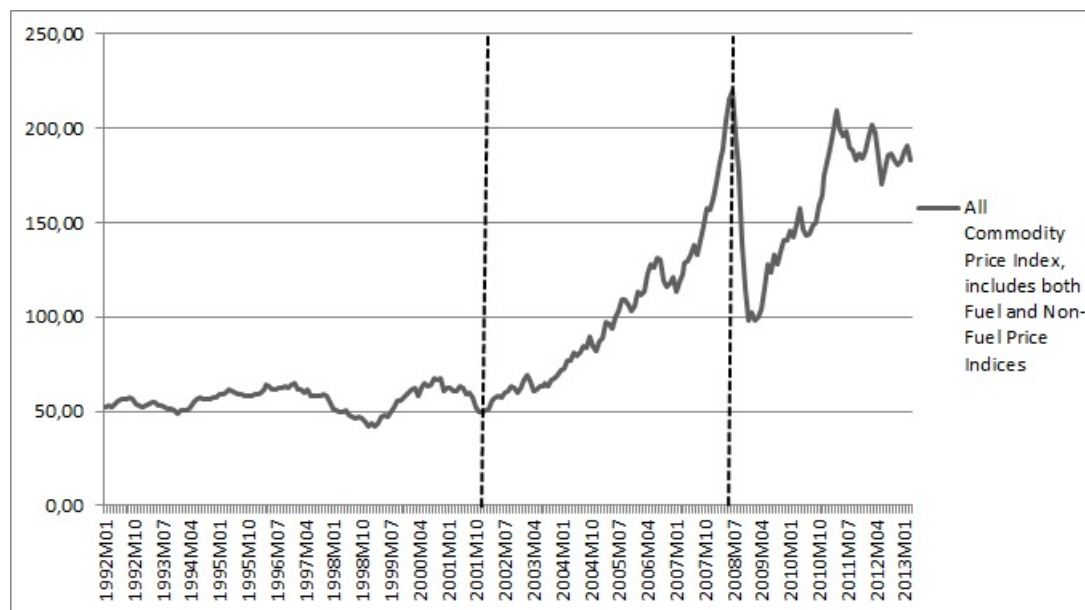
The role of anticipation in the bad sustainability performance of natural resources rich countries has been investigated in Rubio (2004) and Van der Ploeg (2010). Rubio (2004) finds evidence of under-reinvestment in the case of Mexico and Venezuela considering ex-post the evolution of the terms-of-trade. Either investment policy in those two countries is inadequate, or they over-estimated the capital gains from trade. Van der Ploeg (2010) builds on the early findings of Hartwick (1995) to develop an analysis based on the possibility to arbitrage between domestic and foreign investment of the rent, controlling for monopoly power and the structure of domestic property rights. Van Der Ploeg (2011) confirms the findings in the field, stating that “the saving of the nation equals the marginal Hotelling oil rents minus the discounted value of the sum of expected capital gains on oil reserves, expected increases in interest income on net foreign assets and expected reductions in oil extraction costs (due to improvements in extraction technology) plus the amount by which the permanent level of government spending exceeds the current value of government spending.”

More intriguing are his findings about the power struggle over resources. If many domestic groups fight over natural resources and sell them in bigger quantities, increased depletion creates higher prices, forming a vicious circle of increased depletion rate. The conclusion that weak property rights accelerate depletion is similar to the findings of Chichilnisky (1994). The mechanism is however quite different. In the Chichilnisky model, it is below-marginal cost pricing that creates incentives to deplete natural resources faster. In order to see whether natural resources are depleted faster when they are cheap or expensive, empirical work is needed. The effect is likely depend on the institutional configuration prevailing over the extraction. A situation where cheap resources are depleted because an agent can free ride on the rent (because of ill-defined property rights) is consistent with a story where a resource is oversold as many agents need the income for a political struggle.

All in all, Van der Ploeg (2010) provides a better description of the formation of the expectations behind resource depletion. The nature of those expectations provides a rationale for postponing genuine investment but does not solve the problem of consistency in time horizons.¹⁴ Forming rational expectations in the context of high volatility in commodities markets borders on the impossible. Figure 2.2 shows the evolution of the “All Commodities Price index” and its obvious correlation with the business cycle. As such, estimating capital gains boils down to the usual difficulty of producing accurate macroeconomic forecasts. This is instead the whole process of development that needs to be overhauled in its institutional, financial and economic dimensions (Van Der Ploeg 2011). An illustration of this can be found in the resource curse (see chapter 4).

14. This issue is discussed in section III.

Figure 2.2: Correlation between commodities prices and macroeconomic events



Source: Global Economic Monitor (GEM) Commodities

In this section we presented the impact of opening up to trade on optimally managed economies. If world prices are endogenous, trade flows should “die down” after an initial phase of trade as accumulation of produced capital makes the use of non-renewable resources irrelevant. If prices are exogenous, as in the “small open economy” case, trade generates every period gains akin to exogenous technical progress. Those gains should be accounted for in wealth assessment as they may justify under-reinvestment of resource rents in the short run, changing the outlook on unsustainable resources rich economies. This inclusion rests on future prices, which may be hard to estimate in an uncertain context for resource prices. We cited the empirical estimates from [Arrow et al. \(2010\)](#) which suggest that capital gains are important, but meddled with the impact of other variables. Disentangling the numerous trade induced impacts on sustainability remains an empirical question.

Box 2.1: Capital gains from international trade and uncertainty

Open economy settings introduce an element of uncertainty in optimal/sustainable development paths. This uncertainty is born out of the “cohabitation” of domestic conditions of exhaustible resources exploitation with the world system of relative prices. As a price taking economy, a resource intensive country is subject to variations in the price system that reflect the conditions of all the trading partners, beyond its own characteristics. Consequently, the consistency of current prices with a less predictable forward prices path is not guaranteed. As a result, sustainability rules are adapted to take into account those potential gains from exogenous price increases in the future, but cannot do this in an optimal fashion.

II.2 International trade in empirical sustainability

The literature on open economy resources economics propose a rationale for the consequences of international trade on optimal depletion path. This theoretical foundation has also been used in the emerging literature on comprehensive wealth. Following [Asheim \(1986\)](#) and [Hartwick \(1990\)](#) sustainability indicators should be amended for openness. We use Adjusted Net Savings (ANS) as our indicator of sustainability as it is most closely related to our conceptual framework (see chapter I). As a consequence, we review the amendments performed on estimates of ANS as proposed by the World Bank. The basis for the World Bank estimates is the contribution of [Hamilton and Clemens \(1999\)](#). After estimating the relevant current value Hamiltonian which rate of change is the ANS rate, the authors propose to incorporate the current account:

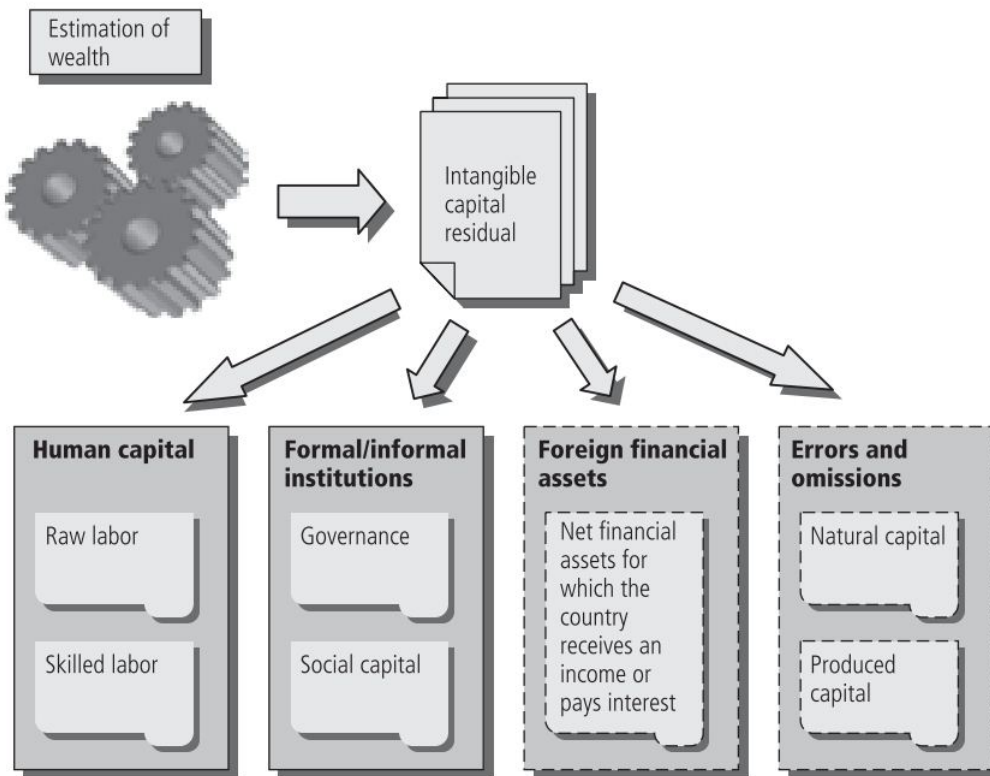
$$A = iA + X - M \quad (2.30)$$

“Net foreign assets A accumulate as a result of exports X and de-cumulate with imports M ” ([Hamilton and Clemens 1999](#)). i is the interest paid on those assets. Exports give the home country a claim on its trading partner by the mechanics of the balance of payments. Symmetrically, imports give the foreign country a claim on the home country. Finally, the interest on the total claims held by the home country are a part of wealth as any income flow derived from a given source of wealth, even from a foreign one. This amendment is already included in the Net National Product (NNP) calculations. Therefore, assessing open economy adjusted net savings only requires to start from the NNP.

It should be noted that this adjustment does not solve the question of the volatility of investment. Foreign Direct Investments (FDI) are defined according to the share of capital owned, not to the length, or the aim of the investment. Therefore, all wealth from FDI is accounted into national wealth, regardless of its volatility. A common sense rule would be to consider as domestic wealth only sunk investment, regardless of nationality, and classify other investments depending on nationality. There is to our knowledge no study in the field of sustainability investigating this point. Still, this simple method is the basic (and broadly used) way to account for international trade in sustainability indicators.

We saw in the previous section the difficulty to discriminate between the impact of trade and other variables in the time dependent term. The [World Bank \(2006\)](#) provides a first answer to this question, although by trying to address another one. In chapter 7 of the report, the authors offer a decomposition of intangible capital estimated as a residual. In this residual are

Figure 2.3: A decomposition of Intangible Capital



Source: World Bank (2006)

regrouped several instruments of wealth (See figure 2.3): human capital, institutional capital, foreign financial assets and errors and omissions.

The term iA is approximated using remittances. To assess the relative weight of the components in intangible capital the authors run a regression using proxies for human and institutional capital:

$$R = AS^{\alpha_S} F^{\alpha_F} L^{\alpha_L} \tag{2.31}$$

With R the intangible residual, A a constant, S years of schooling per worker, F remittances from abroad and L the rule of law index. The α s are the elasticities of the variables with respect to the residual, as in any Cobb-Douglas function. Estimating the model with dummies to control for country income groups, the authors find the rule of law index dominating with 57% of the total, followed by schooling with 36% and remittance with 7%. More than half of the intangible capital is institutional capital, the bulk of the rest being human capital.

This small remittances effect captures the current account impact on wealth. The authors also tried to take into account the time dependent, technical progress-like effect of international

trade. The constant term A in regression 2.31 is country specific, capturing individual effects such as geography and institutional characteristics (on top of those already controlled for by the indexes). The authors then run a regression with the same econometric structure (World Bank 2006, p.113) to estimate actual substitutability between produced capital and exhaustible resources. The term A in this econometric test represents total factor productivity. It is estimated as a decomposition of variables in line with the theory:

$$A = \lambda_1 TOPEN + \lambda_2 PCREDIT + \lambda_3 VA + \lambda_4 PIV + \lambda_5 GE + \lambda_6 RB + \lambda_7 RL + \lambda_8 CC \quad (2.32)$$

$TOPEN$ is trade openness, $PCREDIT$ measures private sector investment and the 6 others are institutional variables for corruption, governance effectiveness, political instability, regulatory burden, the rule of law and voice and accountability. $TOPEN$ is statistically significant and positive. Trade is positively correlated with total output, with a strong elasticity (0.5 or 0.47 depending on the specification). This result, although more of a confirmation of the positive relationship between trade and growth, is consistent with the theory. It also suggests that trade improves substitutability between produced capital and exhaustible resources. In those estimates trade is a statistically significant purveyor of Solow-neutral technical progress.

Those tests were conducted to assess the robustness of ANS as an indicator of sustainability. Due to data limitation, there is to our knowledge only one contribution which investigated the magnitude of capital gains. Hamilton and Bolt (2004) used the Vincent et al. (1997) model to estimate those capital gains using the World Bank dataset. The results by regions are displayed in table 2.2 and the results by income in table 2.3.

The present value of capital gains is relatively small compared to the ANS rate, with the notable exception of Sub-Saharan Africa. Some country level effects reported in the appendix of the article are even more substantial. Beyond this contribution, Pezzey et al. (2006) who followed Pezzey (2004) and Arrow et al. (2010) produce estimates for the overall price of time without differentiating between the capital gains and the exogenous technical change component.¹⁵ Even if calculations were possible, a comparative exercise would be hard to put together because of the weight of uncertainty in natural resources prices. In Vincent et al. (1997), the projections regarding capital gains from oil extraction are largely positive from 1985 onwards. The same country is characterised by negative capital gains in the assessment for year 1999 in Hamilton and Bolt (2004).

The gains from trade prove hard to estimate, making the contribution of exogenous prices

15. Pezzey et al. (2006) presentation of the term $\dot{Q}^R - R^X - R^M$ representing the capital gains suggests that the calculations were made but not reported in the article. Arrow et al. (2010) present the calculation of the capital gains from oil but do not provide the numbers.

Table 2.2: Capital gains by regions

	PV of capital gains, % GNI	Genuine savings, % GNI	Adjusted genuine savings, % GNI
Latin America and the Caribbean	-0.4	6.8	6.4
South Asia	-0.6	11.7	11.1
East Asia Pacific	-0.7	22.1	21.4
Eastern Europe and Central Asia	-1.4	3.4	2.0
Middle East and North Africa	-0.1	-3.3	-3.4
Sub-Saharan Africa	-0.5	0.1	-0.4

Notes: PV – present value; GNI – Gross National Income.

Source: *Hamilton and Bolt (2004)*

Table 2.3: Capital gains by income

	PV of capital gains, % GNI	Genuine savings, % GNI	Adjusted genuine savings, % GNI
Low income	-0.5	5.6	5.1
Lower middle	-0.9	14.9	14.0
Upper middle income	-0.4	9.9	9.5
High income	-0.1	12.7	12.6

Notes: PV – present value; GNI – Gross National Income.

Source: *Hamilton and Bolt (2004)*

to country by country sustainability hard to assess. The point of environmental accounting was to assess country by country sustainability, but also to identify the biggest contributors to environmental degradation. Hence, a first survey by Lee (1996) established the state of natural resources over the planet according to available data. As it became clear that natural resources accounted for a significant part of world merchandise trade (World Trade Organisation 2010) authors started to investigate the natural resources content of trade country by country. The simple but powerful intuition was, (following Martinez-Alier (1995) and the emerging trade and the environment literature) that some countries may be “buying sustainability” (Atkinson and Hamilton 2002) by importing resource-intensive goods and selling human capital-intensive ones. Martinez-Alier (1995) showed that developed countries tend to have higher ANS rates than resource exporting developing countries, and wondered whether this “masked” resource dependence.

This empirical literature opened a still vigorous debate about responsibility, for both resources conservation and depletion. This argument is implicitly about substitutability. If natural capital is perfectly substitutable physically and in money-value, now and over time, then responsibility in a free trade world matter little. One’s losses in natural capital today are one’s gain in produced capital through investment, at home or abroad, over time. *De facto* seamless substitutability via financial markets for natural capital, reinforced by the presumption of capital gains, is precisely what is luring many resources rich countries into un-sustainability today.

This intuition was reinforced by the conclusions of Asheim (1986) who stressed that under endogenous world prices the **consuming** country is responsible for the transformation of natural capital into produced capital, a result reproduced by Hartwick (1995). Sefton and Weale (1996) also demonstrate that part of the optimal depletion path adjustment of exporting countries should be supported by the importing countries. Finally Klepper and Stähler (1998) show that under several sustainability rules, unilateral trade and resource management policies systematically fail to reduce the rate of resource extraction. The corollary is that countries are effectively trying to import sustainability, but only manage to secure unsustainable income gains.

To assess responsibility, a set of empirical contributions used input/output (I/O) tables *à la* Leontief (1936) to determine the resource content of trade flows. Using Multi Regional Input-Output (MRIO) analysis, several studies develop models that trace the resource content of trade flows all the way from extraction to final demand, including trade in intermediate inputs between and within sectors and regions (Miller and Blair 2009). Proops et al. (1999) use a twelve region MRIO, with further decomposition for Western Europe in 17 countries to test the

sensitivity of accounting practices of open versus closed economy models. They conclude that closed economy models overstate sustainability in developed resource importing regions like the US and Western Europe, but understate sustainability for developing resource exporting regions like the Middle East.

[Atkinson and Hamilton \(2002\)](#) also use ANS as an indicator of sustainability, building an MRIO model that functions similarly to an “ecological balance of payments.” Tracing flows of both direct and embodied resources, they reach a similar conclusion: developed countries are major resource importers, but manage to maintain positive genuine savings once those natural resources imports are subtracted. Some, but not all, resources rich developing countries have negative genuine savings, even as natural resources exports are added to their “balance of payments.” This is why [Atkinson and Hamilton \(2002\)](#) suggest that resource importers may wish to assist resource exporters in managing resource sustainability. The difference between responsibility in management and depletion is key here. Importing countries may care for resource management in trade partners for three reasons:

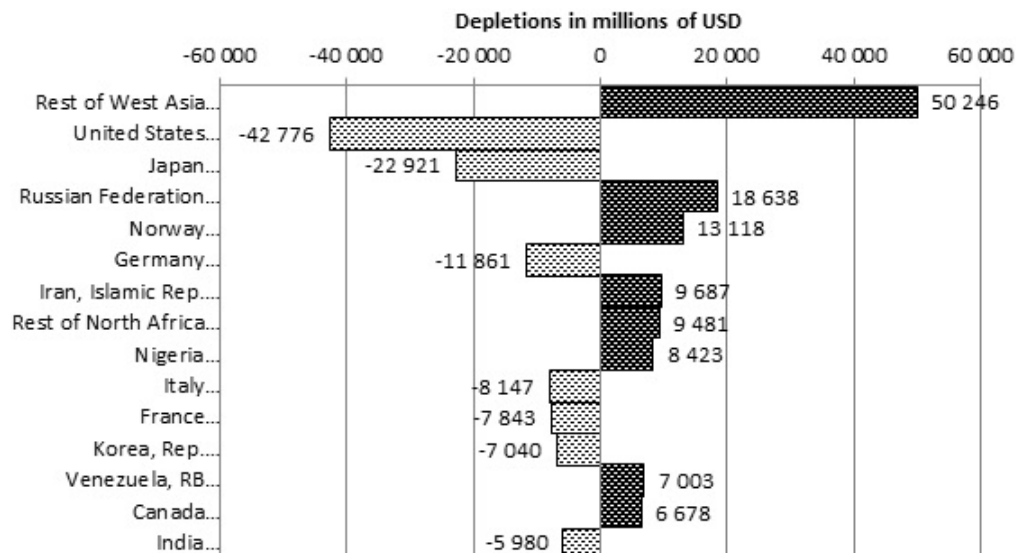
- World resource prices are not shadow prices because of market inefficiency or short term volatility.
- Importing countries have a strategic interest in ensuring a steady supply of resource, which is not guaranteed if resources are managed un-sustainably.
- Importing countries care for ethical reasons about resource management (for example about human right violations related to rent seeking) and support sound management strategies in exporting countries for this reason.

The market inefficiency problem was noted as early as [Asheim \(1986\)](#). The strategic argument is mentioned in [Atkinson and Hamilton \(2002\)](#) and fully developed by [Oleson \(2011\)](#) insisting that the security of importers might be compromised by a reliance on unsustainable trading partners. The ethical argument echoes strongly amongst authors starting with the assumption that international trade creates interdependency and the need for cooperation. Relationships need not be symmetric in this interdependence, and they rarely are. In this setting, cooperation is an ethical imperative in the perspective of sustainable development.

Those considerations are to be disconnected from the responsibility for depletion, which is more of an accounting, and potentially legal concern as the issue is clearly related to property rights and legal responsibility. A country can find it ethically important to cooperate for better natural resources management in exporting countries, without being responsible for a large amount of depletion itself, and vice-versa. Responsibility of depletion is obviously also of prime importance in climate change negotiations, if for example quotas were restricted for those responsible for the greatest share of depletion.

To further the exploration of the responsibility for depletion Atkinson et al. (2012) introduce the term “virtual sustainability” – analogous to the notions of virtual water (Allan 1998) and virtual carbon Davis and Caldeira (2010) – as a way of thinking about the degree of sustainability implicitly embodied in international trade. Using an environmental MRIO with 57 sectors and 112 regions, Atkinson et al. (2012) demonstrate that this distinction can be significant.¹⁶ Figure 2.4 reports the 15 economies with the greatest (dollar value) differences between production- and consumption- based resources depletions. Positive (negative) values indicate net resources exporters (importers) with production based depletions in excess of (below) consumption based depletions. It is important to note that both developed and developing countries feature prominently here.

Figure 2.4: Production- Minus Consumption-Based Resource Depletion (in millions, 2004 USD)



Raw data from GTAP v7, see Narayanan and Walmsley (2008) available online.¹⁷

Source: Atkinson et al. (2012)

Rest of West Asia includes Bahrain, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Occupied Palestinian Territory, Qatar, Saudi Arabia, Syrian Arab Republic, and United Arab Emirates. Rest of North Africa includes Algeria and Libyan Arab Jamahiriya. The concept of virtual sustainability will prove a useful tool in the debate over the responsibility for depletion and its consequences on resource management. The exercise is only limited by the underlying assumptions built on input/output functions. Those tables are built using Leontief production functions, assuming complementarity between factors. It may seem paradoxical to test responsibility for depletion under the assumption of perfect complementarity when most of the

16. Their model incorporates resource depletions in forestry, fisheries, coal, oil, gas, and minerals, and includes deductions for carbon emissions, valued at $USD50/t_{CO_2}$ or just under $USD14/t_{CO_2}$.

theoretical conclusions are derived from models assuming at least perfect substitutability in money-value. Policy implications based on I/O model are potentially biased in this context.

A way out of this dilemma is to use I/O tables in a computable general equilibrium model, to test the evolution of economic specialisation (and resulting trade flows) in a dynamic setting. This approach was first followed by [Bailey and Clarke \(2000\)](#) who used the dynamic general equilibrium approach to build sustainability scenarios over fifty years. The base model is the GREEN model developed by the OECD. The standard scenario delivered continued sustainability over time, and only the most pessimistic scenario (which included no energy saving technologies or backstop fuels) predicted un-sustainability for the US and Brazil only, alongside weaker growth. [Turner et al. \(2011\)](#) propose a CGE model for carbon emission to demonstrate that un-sustainability for Wales (assessed using the carbon footprint) comes from the export orientated steel making sector. This result is interesting as it suggests that the finality (domestic or foreign markets) makes a difference when assessing sustainability. It is another aspect of the responsibility for depletion issue.

In this section we presented the empirical evidence on the capital gains from international trade. Capital gains are theoretically well defined, but they are hard to predict as they require a perfectly known path for future prices. Attempts at forecasting commonly result in errors in both magnitude and sign of the capital gains, making those quite unreliable to guide resource management policy. More successful are the attempts to estimate capital gains jointly with others productivity improving variables. In the wake of those difficulties, a second important stream in the literature decided to focus on the measurement of “virtual sustainability”, the resources content of trade. Many countries have a stake in sound resources management for various reasons and this literature proves helpful in bringing facts about the trade-adjusted sustainability positions of resources importers and exporters.

Box 2.2: Responsibility for depletion and international substitutability

The concept of “virtual sustainability” emphasises the challenge brought by international trade in terms of responsibility for depletion. Under international trade, the seamless exchange of instruments of wealth which differ in nature is possible. International trade theory makes the money-value exchange of goods produced under different factor intensity a source of comparative advantage. The seamless exchange should be reconsidered if exhaustible resources are asymmetrically traded so that international trade fosters wealth erosion in natural resources intensive countries.

III Trade and sustainability: a synthesis

In this final section of the chapter, we present the last two issues in open economy sustainability. We first discuss the problem of the time horizon when assessing trade impacts. We saw that depending on the assumption regarding world prices (exogenous and endogenous), capital gains differ in nature and magnitude. We believe this question to be better addressed through the perspective of trade liberalisation. A growing line of evidence suggests that the timing of trade liberalisation matters, and that the consequences of this one-off decision could be lasting.

The question of trade liberalisation can be associated with the issue of time consistency. As presented in chapter 1 section II.3, steady-state analysis with its emphasis on convergence is not best-suited to assess shocks with lasting structural consequences. The structural rules presiding over long run convergence should be reassessed regularly as shocks may generate hysteresis. The same limit makes the joint analysis of trade and sustainability in a dynamic setting more complicated: trade shocks (variations in volume and content) are short term problems compared to the usual sustainability horizon. This problem may call for at least temporary management of trade flows using trade management instruments. In this perspective, we review the contributions on trade management instruments and sustainability, concluding with Ederington and Minier (2003) that trade and environmental policy are *de facto* already intertwined.

Finally, we present a conceptual framework for trade and sustainability, similar to the one presented in chapter 1 section II.2. While we certainly agree with the practical distinction drawn in the literature between international trade and open economy, we argue for a common set of principles when exploring the links between trade and sustainability. This set of principle will be derived from the framework exposed in chapter 1. Following those principles will maintain consistency in the analysis. One lesson that seems to be drawn by many authors in the literature is that trade is a complex mechanism, in itself a synthesis of closed economy effects tackled in a different context. Those effects include property rights issues, specialisation, weak versus strong sustainability and responsibility for depletion.

III.1 Trade liberalisation and trade policy: challenges for sustainability

We saw with Hartwick (1995) that a marginal difference in resources endowment could generate trade flows with consequences on the sustainable path. From this observation, it is

legitimate to inquire about the impact of trade liberalisation on sustainability. The answer is likely to depend on the way trade would be modelled. The essence of a trade model is to estimate the gains from trade (see notably [Arkolakis et al. \(2012\)](#)). The results in the trade and the environment literature are in favour of trade liberalisation, defined as shifting from a state of autarky to a state of free trade. Fewer articles investigated the possible relevance of the *timing* for such a move.

The literature on income convergence addressed this issue, mostly based on Heckscher-Ohlin patterns of trade. A first contribution by [Atkeson and Kehoe \(2000\)](#) stressed the difference between “early bloomers” and “late bloomers”. Their model picture a world of small open economies, similar in their preferences, technology and starting capital stock. The early-bloomers reach the steady-state before the late-bloomers start to develop. In this setting, the late bloomers converge to a permanently lower level of output per capita. Lack of income convergence is in itself a telling result. More interesting are the mechanisms behind this result.

Both countries are composed of two sectors. In line with the factor price equalisation prediction, there are more than one capital-labour ratio compatible with equilibrium. In a one sector model only one ratio is compatible with steady-state output. This result is a direct consequence of the separability assumption in HO models, by which the amount of produced capital has no impact on the rental rate. It produces a situation where the signals sent by world prices and endowment distribution get late bloomers stuck in a cone of diversification which promises them permanently lower output. The timing of trade liberalisation is as important as the measures of trade liberalisation themselves. A second contribution by [Bajona and Kehoe \(2010\)](#) furthers this initial finding, showing that convergence in income depends on the elasticity of substitutions between the goods produced in the two sectors.

Those findings deserve to be brought to the light of the institutional analysis from chapter 1. ? describe at length how the opening of transatlantic trade constitutes a critical juncture in institutional terms. [Yi-fu Lin \(2012\)](#) presents the failure of newly independent countries in the 1960’s to develop an indigenous industry based on imports substitution. Faced with the critical juncture of trade liberalisation, a developing country has no choice but to enter trade in line with its comparative advantage and specialise. The dividends of specialisation should then be used to develop new high return specialisations and to catch-up this way with the level of development of trading partners.

The findings of [Atkeson and Kehoe \(2000\)](#) are a big question mark on this last step, depicting countries stuck in their early specialisation and incapable of catching-up. The observer is left with the uncomfortable choice of choosing between blaming the logic of specialisation or, noticing that a handful of countries succeed in crossing the threshold, dissecting the reasons

behind this success. ? and Yi-fu Lin (2012) concur in placing their bets on institutions. If the economy opening-up to trade is “ready,” (able in its very structures to make the most of income gains from trade that is) the outcome is likely to be positive and lasting.

A suitable insertion in international trade, in terms of timing and specialisation is critical for structural change. Structural change is the critical process under which the economy transfers its reliance from natural capital and labour to more sophisticated (or just transformed) instruments of wealth. Le Van et al. (2010) explore this necessary transition and stress the role of the initial level of capital and pure rate of time preferences in escaping natural resources dependence. Natural resources management in the wake of trade liberalisation is critical to the future of the country. If the comparative advantage of the developing country comes from exhaustible resources, it will receive an important windfall that needs to be properly reinvested. Lacking proper resources management mechanisms, resources rents are likely to be wasted through wasteful investments or unsustainable consumption, as international demand will not abate (Atkinson and Hamilton 2002).

There are still doubts over the suitability of trade liberalisation regarding natural capital. Bouët et al. (2005) show how trade liberalisation might not be to the benefit of agriculture dependent developing countries. Bouët et al. (2010b) then study the conditions under which trade liberalisation might be profitable for the least advanced countries. In the timing of development (and structural change), management of the years separating specialisation gains into resources intensive goods from diversification into produced capital is critical. This management should be properly assessed in models of sustainability. Unfortunately, sustainability models do not contemplate the potentially destabilising effects of the timing of trade liberalisation. Mostly comparative statics models frame the model under the “Dutch disease” and the resource curse (see chapter 4 section II).

Here lies the second problem regarding the timing of trade liberalisation. Sustainability issues are assessed in inter-temporal optimisation models, over an infinite horizon. Compared to this kind of horizon, those critical years of transition do not weight much. The limit of using a time dependent variable as a proxy for capital gains and trade impacts appears clearly here. Models of inter-temporal optimisation are applied on shorter horizons¹⁸ but only as a proxy and still require convergence as presented in chapter 1 section II. What is needed is a model nested in the broader sustainability models (broader in the sense of the classification in figure 1.10), a tool of “meso-economic analysis” consistent with the larger sustainability message.

As short-to-medium term shocks may have a deep impact on specialisation and structural

18. Pezzey et al. (2006) use 20 years and the World Bank 2006, 2011 typically uses 25 years of future prices.

change they should be rationalised into long run sustainability. This challenge is one of the core question of the literature on structural change. Some contributions assessed the impact of trade openness and natural capital availability on structural change. [López et al. \(2007\)](#) find no relationship between resource abundance and economic growth in the context of structural change. [Antoci et al. \(2009\)](#) are less optimistic, observing that strategies based on natural resources are likely to yield less favourable outcomes than those based on labour and produced capital. [Lederman and Maloney \(2003\)](#) find resource abundance to have a positive impact on growth but export concentration to have a negative impact, suggesting that the relation between domestic engines of growth and export specialisation is ambiguous.

More work is needed to build on those promising leads. Still, the case for delaying trade liberalisation depending on the international context and the domestic structures is strong. countries liberalising trade are at risk to be trapped in an unsustainable cone of diversification. For example, [Bouët et al. \(2010a\)](#) question the environmental benefits of biofuel production, in terms of land use reallocation in producing countries. The contradictory evidence on the relationship between specialisation, sustainability and growth certainly calls for precaution in the way trade liberalisation is handled. In the context of ill-enforced property rights and institutional failures, some authors have argued for a review of the usefulness of trade policy instruments.

Although those tools are second best tools in a perfectly competitive context, they may perform better than market mechanisms in kakotopia. In countries plagued by the resource curse, trade management instruments are likely to have a net negative impact as they may be used to protect monopolies and political rents. However, trade management instruments are also shown to benefit both economic growth and environmental quality, particularly when open access resources are involved ([Flaaten and Schulz 2010](#)). Proponents of an active trade policy are getting more vocal over concerns regarding absolute scarcity. [Bouët and Laborde Debucquet \(2010\)](#) show how export taxes can be used to stabilise domestic prices in large countries with a comparative advantage in agriculture in the context of a food crisis.

Regardless of whether we retain a weak or strong sustainability perspective, the effect of trade on sustainability clearly depends on trade policies and institutions. The structure of taxes reflect the transmission of those policy variables to their objectives. An important part of the economic literature has argued that tariffs should be avoided on efficiency grounds ([Baumol and Oates 1988](#), [Burguet and Sempere 2003](#)). Nonetheless, [Lee and Roland-Holst \(1997\)](#) show that under an inefficient tax system, trade liberalisation can lead to increased emissions. Can efficient tariffs render trade liberalization and environmental protection simultaneously achiev-

able? Hecht (1997) reviews the literature on tariff escalation¹⁹ and the environment, finding no evidence that escalation exacerbates degradation or reduces efficiency.

This consensus is nonetheless contested, especially after the Seattle meeting of the World Trade Organisation (WTO) (Tisdell 2001). A good starting point is offered by Kellenberg (2009) who shows that when trade, environment and property rights are considered simultaneously, relaxing environmental regulation can stimulate economic growth. Okumura and Cai (2007) show that if all factors of production are essential in the production function (i.e. complementary), countries will tend to deplete foreign exhaustible resources first (via imports) as a way to protect national instruments of wealth. Shimamoto (2008) shows that tariffs can promote sustainable forest exploitation if marketable commodities and forest externalities are imperfect substitutes. Brander and Taylor (1998) show that under an HO-type setting where one sector relies on an open access renewable resource, export taxes can have a positive economic, environmental and social effect. This result is confirmed by Flaaten and Schulz (2010) who add to the conservation gains for the renewable resource consumption and production gains for the domestic economy with an export tax. The importance of asymmetric information to legitimise protectionism is also stressed by Bouët (2005). Although the two sets of findings appear contradictory, closer examination shows complementarity in results and recommendations:

- Reducing tariffs is likely to bring efficiency gains by reducing dead-weight losses and local monopoly rents accumulated under those tariffs. Lower tariffs bring more stringent environmental regulation via EKC-like effects.
- Strategic, circumstantial tariffs can be used to address a particular problem (such as over-exploitation of a common-pool resource) when no other instrument is available or proper enforcement of environmental regulation impossible.

Trade policy instruments are second best economic tools: they should therefore be used when no first best is available. They can be efficient transitory tools in periods of general trade liberalisation as safeguard measures in conjunction with quotas. Moreover, they can be a tool for reducing global pressure on stressed natural resources. When the opportunity of trade management instruments is raised, the trade-off between global gains from trade resulting from less protection and local gains in environmental and social terms must be properly assessed.

Trade Pessimists such as Daly (1996) and Muradian and Martinez-Alier (2001) consider that “Eco taxes” (or more accurately Eco Tariffs) should be imposed systematically as a way to internalise trade partners’ externalities. If externalities are associated with the production of goods beyond the particular cases enumerated above, this policy could also improve efficiency.

19. “tariff escalation refers to a pattern of import duties which rise with the level of processing of the goods purchased” Hecht (1997).

To prevent trade wars, trade management instruments should be agreed at the global level. Traditionally, responsibility for assessing instrument merits and legality falls to the WTO, which allows the use of safeguard measures on environmental grounds, but only as an exception to the rule. The burden of proof currently lies with those opposing trade on environmental grounds, and many stakeholders contend that the WTO disproportionately favours trade over the environment.

In response, the idea of a “World Environmental Organisation” to address global issues related to the environment and sustainability has been on the academic and political agenda for years, but with little real progress. Similarly, the acknowledgement of an environmental “responsibility to protect” global resources and ecosystems for present and future generations triggered little political action (particularly in times of austerity and economic stagnation). This section is written under the assumption that trade policy will continue to be debated at the global scale in the WTO. But the current stalemate over the Doha Development round illustrates the fact that in international trade the interests of developed and developing countries often diverge, and reaching multilateral consensus may be increasingly difficult. In the context of raising concerns about the sustainability of agriculture and more generally strategic natural resources management worldwide²⁰, beggar-thy-neighbour resource policies will become a permanent risk. In this perspective, resource-deprived economies are likely to lose in bilateral trade agreements compared to multilateral ones. Sustainable development and sustainability are not possible without a “sustainable trade policy.”

Box 2.3: Structural change and the timing of trade liberalisation

The timing of trade liberalisation matters as trade liberalisation means both a shift in domestic patterns of production and making domestic instruments of wealth available for international demand. Although trade liberalisation usually results in efficiency and consumption gains, countries with marked comparative advantages may get trapped in a narrow specialisation, especially in natural capital intensive goods. This will then reverberate on the whole development path, durably altered by this short-run shock. Should the shift in production patterns implied by trade liberalisation deplete some instruments of wealth too quickly, the transitory use of trade management instruments is warranted.

20. See the latest [Chatham house report](#) on managing resources.

III.2 A model for trade and sustainable development

In this chapter we review the relationship between international trade and sustainability, and observe that doing so requires the convergence of trade theory, natural resources economics and both sustainability paradigms. We put into perspective differences between open economy sustainability and trade and the environment. We stress the potential role of trade policy instruments in solving theoretical inconsistencies and empirical difficulties emerging within and between those approaches. We concluded that despite recent efforts to quantify the effects of trade on sustainability, it remains a relatively open research area.

Trade theory brings important lessons and relatively robust results relevant to sustainability. Countries abiding by the logic of comparative advantage can expect income gains and technological spillovers that enhance global welfare. There are, however, important caveats to this story. The magnitude of the gains from trade depend on the conditions (timing, endowments) under which a country liberalises trade. Countries could end on the “wrong” side of specialisation, trapped in the production of low value-added, exhaustible resources intensive goods. We believe those mixed conclusions support our original intent to design a “framework for trade and sustainability”. We will now offer a first sketch for this framework and use this as a justification for the work undertaken in the remaining chapters of this thesis.

The key components of our sustainability framework are highlighted in boxes through chapters 1 and 2. We use those components to present the trade-induced changes in our sustainability framework in chapter 1 subsection II.3. In box 1.6 we stressed how subsidiarity naturally follows from the precautionary principle, while in box 1.5 we presented the role of institutions for sustainability. The very existence of international trade creates a potential inconsistency in our presentation of those notions. International trade theory studies the exchange of goods and services in a world that is neither perfectly integrated (as understood in an analogy for a functional country) nor a collection of autarkic (island-like) countries. This situation of imperfect integration creates a “grey area”, traditionally ruled by country negotiations.

Two starting points are usually used to analyse this “grey area”. One perspective is to consider the world as a whole, investigating how agents can allocate resources in the most effective manner under some negotiated institutional constraints. In this perspective, international trade does not differ in essence from interregional trade. The world is best described in the “angel parable” from Samuelson (1949): an open space burdened by non-deterministic²¹ borders that should ideally be overcome and/or suppressed for the sake of efficiency. International trade is in the perspective the main tool of a two steps strategy.

21. In the sense that they are not structuring the analysis and could be removed.

The first step is to create an international optimal allocation of resources using trade. Incentives to do this exist as consumption and welfare gains from trade can be expected. The main obstacle is to overcome friction, whether institutional (national borders) or physical (transportation costs). One needs also to control allocation for undesirable outcomes such as pollution havens. In the second step (once a steady-state is reached) private incentives coincide with social incentives at the global level. Global “bads” (such as global warming) can be tackled efficiently via market mechanisms or other newly created global institutions. Under this scenario, consistency with the closed economy framework from chapter 1 is restored via ever increasing integration. As a consequence, international trade issues can be reduced to closed economy issues over time.

The second perspective, routed in a more traditional country-based approach to sustainability, sees the world as a collection of countries trying individually to reach sustainability. In this perspective, trade is more a coordination mechanism, bringing benefits but also costs and constraints on the domestic strategy. This perspective is also grounded in the observation that the state level is still the most relevant level for sustainability issues (law enforcement, redistribution, natural resources management policy).

Models developed by proponents of this approach are more of the “open economy sustainability” kind, focusing on domestic optimal planning under (usually exogenous) world prices and the impact of trade variations on national economies. If each country reaches sustainability individually, the world will be sustainable under the assumption that each country incorporates in its strategy a “fair share” of global bads (fish overexploitation and ocean acidification to name only two). The obvious challenge against this perspective is the need to agree to first and then enforce rules corresponding to the global optimum at the country level. Any coordination equilibrium includes an opportunity for free-riding.

Those are the two sides of sustainability: focusing on optimal trade may yield income gains and improve the global outlook but leaves some countries worse-off, or shouldering a disproportionate share of the global un-sustainability. Conversely, focusing on country by country sustainability may lead to beggar-thy-neighbour trade policies or lead observers to miss a potential “imported sustainability” in an otherwise favourable domestic picture. Hence the existence of international trade comes from imperfect integration while imperfect integration creates inconsistency in our framework for sustainability.

This inconsistency comes from the impossibility to organise natural resources management under the subsidiarity principle (see box 1.6 and figure 1.10). inconsistency has consequences for the ability to tackle uncertainty and select optimal paths as (to take the second perspective) imperfect integration changes the setting of domestic prices. As domestic instruments of wealth

face a global demand reacting to conditions in other countries, uncertainty increases. This uncertainty makes the management of capital gains particularly complicated (box 2.1). It should be noted that increased uncertainty makes the use of scenarios and counterfactual studies even more necessary, as sustainable paths need now to be computed contingently to a broader set of exogenous conditions.

We will illustrate the consequences of this for the maintenance of wealth (box 1.2) and constant consumption over time (box 1.3) using an example. Let us consider a closed economy that is relatively well-endowed compared to the world average in a given (exhaustible) natural resource. This economy previously ran under the preferences of its agents without economic interactions with the rest of the world. Still, we assume that those agents have preferences similar to the rest of the world nonetheless. Hence, this economy is relatively more diversified compared to the rest of the world, so as to produce a wide range of goods and services and satisfy local demand.

The decision is made to open-up to trade to benefit from a) specialisation gains in the HO logic, b) productivity gains from the insertion in the global supply chain, by increasing returns to scale and attract foreign direct investments and c) to satisfy potential global demand for the domestic exhaustible resource at a higher price than the domestic price (the global market is assumed to be bigger than the domestic one). We assume also that trade liberalisation is a one-off decision but the domestic economy needs time to make the adjustment in consumption and investment decisions. The domestic economy will take world prices as given, as in [Asheim \(1986\)](#) and the second scenario in [Hartwick \(1995\)](#). It should therefore take capital gains into account and adapt natural-capital use policy accordingly.

We consider the impact on factor endowments using a standard HO setting with two countries, two goods and two factors (produced capital and exhaustible resources).²² We suggest a simple comparative statics exercise where good x_1 is relatively intensive in produced capital and good x_2 is relatively intensive in the exhaustible resource. Consider the impact of an increase in the world price of good x_2 as a result of trade liberalisation:

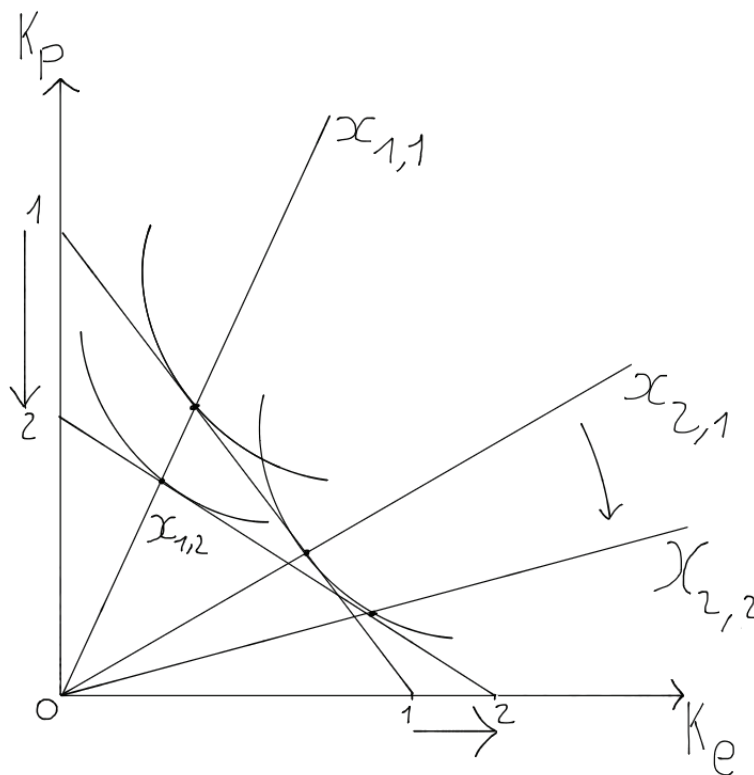
- As the price of the exhaustible resource intensive good goes up, resources are reallocated to the sector of good x_2 so that the production of good x_1 falls and the use of exhaustible resources increases (Stolper-Samuelson theorem).
- This increase in the use of the exhaustible resource should trigger a more than proportional increase in production of good x_2 , following the [Rybczynski \(1955\)](#) theorem. All in all, trade openness creates a more than proportional increase in exhaustible resources use in

22. In a standard HO model, endowments are constant. The dynamics described here are to be understood as illustrations of the dynamic impacts of the canonical theorems (see chapter 3).

a dynamic setting.

The transition from autarky (state 1) to free trade (state 2) is presented in figure 2.5. Without specifics, the net effect on wealth is conditioned by the reinvestment of the rent from exhaustible resources in other instruments of wealth. Still, it is clear that international trade increases specialisation. Beyond trade liberalisation, trade in an HO setting with capital gains has a quasi-ricardian productivity improving impact. The nature of those productivity gains is conditioned by the distribution (and redistribution) of the rent. With limited inequality, productivity gains are likely to be Solow-neutral. A shared windfall favours investment in all sectors, resulting in general productivity gains. But would there be strong inequalities between rent owners, then productivity gains are likely to be concentrated in the exhaustible resource sector as in the resource curse. This decision is sensible from an economic perspective as it is the only sector able to maintain competitiveness internationally (see chapter 4).

Figure 2.5: Trade liberalisation with a natural resources intensive sector



Source: Author

This investment strategy could strengthen the country's comparative advantage, increase income gains and entrench specialisation. Productivity gains also make extraction more efficient and/or less costly. The necessary development of up-market comparative advantages in

then delayed, while the “deadline” represented by the stock is brought closer²³. The optimal depletion path in autarky was calibrated on domestic demand and domestic preferences. Even if we assume that domestic and world preferences are the same²⁴ the added world demand will skew the optimal depletion path towards extraction. The overall impact should therefore be accelerated depletion even if the new world interest rate is less than the former autarky interest rate.

Once the domestic economy improves its competitive positions in other sectors, additional rents can be invested domestically. But why would this domestic economy diversify its production? Trade encourages specialisation as a source of income gains, while sustainability would require diversification away from natural capital as a way to preserve the stock and its services (Hartwick 1977). The logic of the comparative advantage is based on an increased division of labour at the international scale. Productivity gains are obtained through increased specialisation, which goes against the implicit diversification advocated by the substitution in the Hartwick rule. As a consequence, trade generates strong composition effects on comprehensive wealth, which makes assumption on money-value and physical substitutability critical (see box 1.4).

The factor constituting the comparative advantage will be used more intensively. This will in turn increase income for the owners of that factor. There is a strong empirical correlation between high rents from natural resources and comparative advantage in natural resources (see figure 4.2 in chapter 4). Hence, international trade may create incentives regarding the composition of wealth that goes against sustainability rules. This impact of international trade on wealth composition can be offset by domestic reinvestment of the resource rent, impacting favourably other factor’s income. But in an open economy setting, as in Van der Ploeg (2010), rents can also be invested abroad.

It is likely that at this stage, better opportunities of investment are available in the rest of the world than in the domestic economy. This is especially likely if the rest of the rest of the domestic economy is uncompetitive compared to the natural resources intensive sector. At this point, international trade seems more likely to generate the kind of rentier economy described by Van der Ploeg (2010) than diversification in comprehensive wealth. One could argue that the domestic economy still get income from its overseas investments. But why would this income be reinvested domestically, let alone outside the natural resources intensive sector? Still, against

23. Although if the natural resource price is reduced by diminished extraction costs, the backstop is pushed further in time.

24. We assume notably similarity in their preferences regarding the environmental degradation resulting from the exploitation of resources. According to the literature on trade and the environment and informal regulation (Pargal and Wheeler 1995), this is likely to be untrue.

the logic of specialisation, diversification should also be supported because of uncertainty over actual substitutability (box 1.4).

The logic of capital substitutability is justified by the standard tenets of resource optimism (Neumayer 2000, for an excellent review), historical experience (Krautkraemer 2005), and empirical estimation (Markandya and Pedroso-Galinato 2007, World Bank 2006). Extending beyond domestic borders, trade presents further opportunities for substitution and enhances efficiency; international carbon trade and biodiversity offsets are two such examples. We stressed the limit of this logic under autarky in chapter 1. The problem remains under free trade: organising markets providing *de facto* value-substitutability between different instrument of wealth does not provide information regarding physical substitutability and neglects opportunity costs.

Market offsetting is based on the same theory of value in open economy and suffers from the same flaw regarding intragenerational equity. Neumayer (2010) is right to stress that the actual amount of substitutability is the last and principal bone of contention between environmental and ecological economics. In the face of uncertainty, organising international markets on the basis of perfect substitutability clearly violates the precautionary principle. It also makes the potential violation of intragenerational equity worse, as there are virtually no international redistribution mechanism and those are anyway short circuited by domestic institutions.

From an intergenerational perspective, as long as the resource windfalls are reinvested into other forms of capital and income is guaranteed, there is no difference between domestic and foreign investment. Intergenerational challenges lie in making adequate comprehensive wealth investments to account for traded resources, and addressing potential capital gains, which have the ability to trade consumption and investment over time. From an intragenerational equity perspective, diversification and specialisation are not perfect substitutes. Neither are domestic and foreign investment.

Non-resources factors already see their income reduced by the first reallocation effect after trade liberalisation. They can then be deprived from the “trickle down” effect caused by domestic reinvestment of windfalls from the natural resources sector. This composition effect reduces the use of other factors in the rest of the economy without rising by the same extend (because of relative intensity) employment in the resources intensive sector. This effect is then amplified by the Rybczynski effect, increasing more than proportionally the size of the exhaustible resources sector. In the Copeland and Taylor (1994) model, this effect played for the environment as the use of pollution decreased. It plays against sustainability here by rising natural resources use.

Natural resources being scarcer than other factors, the general prediction of the Stolper-Samuelson theorem is likely to come true. Trade liberalisation results in lower income for the more abundant factor in both regions, so that both produced capital and labour might eventually be worse-off. Trade will provoke a reallocation of resources across sectors and is therefore likely to offset the previous balance between interest groups in the country: the potentially positive impact of trade is dependent on the structure of ownership and resulting rent capture. Trade may have little positive impact if lobby groups are able to use trade management instruments or legislative influence to protect against distributional effects.

Dealing with wealth inequalities is the core intragenerational challenge of international trade. Despite global income gains, trade liberalisation results in widening inequalities between factors and potentially narrowing inequalities between countries. In this, international trade is also a challenge for the imperative to keep consumption constant over time when agents have property rights over dissimilar bundles of instruments of wealth (box 1.3). Even if foreign investment of the rent is temporary, a generation worth of human capital can be wasted by the delayed domestic reinvestment. In addition, countries also face an increase in the likelihood of future investment to be wasteful, by lack of domestic demand and skills.

Reallocation from specialisation in international trade empowers owners of natural resources relatively to owners of other instruments of wealth. This assumption is supported by the recent findings of Carmignani (2013), studying the relationship between resource abundance and inequalities. It should be noted that reallocation towards the natural resources sector also reinforces the power of resources owners on institutions. Growing inequalities in income diminish the general inclusiveness of institutions, breaking the virtuous circle presented in figure 1.5.

According to ?, if institutions are politically and economically inclusive, then domestic demand generated by the resource sector should increase possibilities of investment in human capital in the population, generating other comparative advantages from the newly trained population. From there, the accumulation of domestic produced capital should start. Still, if intragenerational equity is non-existent or discouraged, rents may and will stay invested overseas. Lack in intragenerational equity creates a breach in intergenerational equity as the current generation is frustrated from potential social accumulation of wealth.

The consequences of international trade on within-country distribution of wealth and income came under close scrutiny on employment grounds. The second globalisation, accelerating with the fall of the Berlin wall, saw an increase in job losses in the manufacturing sectors of developed countries. Wood (1994) insisted that in line with the Stolper-Samuelson prediction, inequalities would rise with globalisation as labour would be less demanded in developed countries. Another

potential culprit for those losses was technical progress, pushing to substitute produced capital for labour. Testing the idea that firms could shed jobs by increasing productivity against a direct trade-induced composition effect, [Cardebat and Teiletche \(1997\)](#) find mixed evidence, if anything slightly in favour of the technical change hypothesis.

Still, later contributions conducted on broader samples give more weight to the impact of international trade on sectoral composition. As reported by [Cardebat \(2009\)](#), both the [World Trade Organisation \(2008\)](#) and the International Monetary Fund (IMF) believed at the end of the last decade that international trade could take responsibility for almost half of the job losses over the decade. [Chusseau et al. \(2008\)](#) review the theoretical and empirical literature and find that international trade increases inequalities mostly via incentives to outsource production abroad. Increasing inequalities from increased specialisation are a major sustainability issue as reduced within-country intragenerational equity impacts negatively political inclusiveness via reduced economic inclusiveness (see [box 1.5](#)). It also violates the Rawlsian argument regarding the “original position”. Strong redistribution mechanisms become critical to ensure sustainability, which becomes also less likely as the income and wealth gaps widen.

Those redistribution mechanisms are needed for the protection of the rights of current domestic generations against foreign generations, and the rights of future domestic generations against all present generations. This protection is theoretically guaranteed by efficient market mechanisms, or efficient hedging in the face of uncertainty. Yet, basing a strategy on the ability of international markets to yield a) a consistent system of current and future relative prices and b) send the right incentive in terms of instruments of wealth allocation should raise concerns following our presentation.

The elements we presented question the suitability of specialisation in an exhaustible resource as much as they question specialisation away from labour. Countries will get into a cone of diversification, related to their endowments. As an industrial specialisation intensive in a given resource is chosen, there are large switching costs (and a risk to become uncompetitive) in changing specialisation. The country is likely to be stuck into a production pattern that will exhaust its resources and hamper structural change in wealth instruments. This resources-abundant country is then likely to fail to diversify its productive base into several sources of capital.

Focusing on the productivity-improving side of trade while occulting the potentially damaging composition effect is therefore reckless. The irony in our analysis is that the very mechanism of comparative advantage that is the source of initial development should be slowly overthrown to reach sustainability. Once the social need for sustainability is accepted (see [box 1.1](#)), it should be clear that trade-induced composition effects cannot be relied on to trigger sustain-

able structural change.

Those links between intragenerational, intergenerational equity and international trade have already been unearthed in the literature, although to our knowledge their importance for sustainability has not yet been presented in an integrated framework. Although awareness of those issues can be assumed, the translation of this awareness into a strategy for sustainability is often puzzling. Trade mechanisms are usually advocated to be left alone so as to provide productivity gains while “structural reforms”, are assumed to yield to necessary push for diversification. This boils down to assuming that trade cannot go against the goals of those reforms. Assuming (maybe kindly) that structural reforms are about increasing political and economic inclusiveness, there is room to question the efficiency of leaving trade incentives unscathed in the process.

How to develop those other sectors, how to create the economic incentives to distribute or redistribute income from wealth beyond institutional reform? A first fact coming to mind is that the existence of sectors not compatible with comparative advantages is justified by transaction costs. In [Dornbusch et al. \(1977\)](#) where trade is determined by a ricardian pattern, the existence of transaction costs determine the existence of a set of non-traded goods and sectors, preventing complete specialisation. Transaction costs are a first source of diversification as they create the rationale for developing a domestic industry in goods that are too costly to import.

One could argue that those theoretical results are obtained under the restrictive assumption of factor immobility. We saw when testing for the PHH against the traditional FEH that larger-than-present regulation-induced costs would be needed for a massive reallocation of production across countries. This may change quickly should environmental costs (real or regulatory-induced) increase. But in the meantime, substantial trade costs, whatever the source, make the case for industries (especially immobile industries) to be developed on domestic soil.

A second rationale for diversification lies in investment in instruments of wealth. Instruments of wealth are assumed to be perfectly money-substitutable. Investments imply comparable returns as well as different sunk costs and opportunity costs. It is also impossible to invest in exhaustible non-renewable resources beyond efficiency and exploration investments. Those investments typically involve sunk costs.²⁵ Concerns over substitutability, sunk costs and resilience should be taken into account when comparing the relative returns of instruments of wealth. The development of option values to complete current estimates of opportunity costs could be promising. Returns should be balanced against not only immediate environmental and social costs, but also composition costs associated with increased specialisation based on a

25. Sunk costs associated with natural capital involve the destruction of ecosystem services and the definitive exhaustion of some physical elements.

dwindling²⁶ instrument of wealth.

The opportunity cost of investing in labour/human capital should be considered beyond traditional returns. Although the country may not have a comparative advantage in human capital, human capital provides a hedge against the likely evolution of specialisation. A similar property is observed with some forms of money capital²⁷ and produced capital involving the least sunk costs. Opportunity costs are represented by the fact that investing in one specialisation means there is no investment in any other specialisation. Under uncertainty, only time can tell if the sustainable benefits of investing in one specialisation are greater than the opportunity costs represented by the benefits of developing other specialisations. At some point the trade-off presented here makes hedging by investment in other instruments of wealth necessary.

The consideration of those opportunity costs opens new perspectives on the links between subsidiarity, structural change and the timing of trade liberalisation. An early opening to international trade based on a comparative advantage defined by a handful of instruments of wealth looks much more costly than usually assumed (see box 2.3). This scenario makes an important specialisation of the economy quite likely, with the political, sunk, opportunity costs associated. This scenario makes massive transfers of “virtual instruments of wealth” likely, with all the problems regarding money-value substitutability and rent extraction that this implies (see box 2.2). The safe move from here is to purely and simply delay trade liberalisation until the distribution of instruments of wealth is less asymmetric.

Still, this is potentially unsatisfactory as some gains from trade can be expected. It is also possible that for strategic reasons or because of enforcement costs, prolonged autarky is not an option. This is where the subsidiarity principle is critical. If the domestic economy is properly organised under the subsidiarity principle, it is possible to let international trade shape specialisation at the national scale while keeping some room for manoeuvre at the regional scale. This possibility emerges from the existence of transaction costs, local preferences and international economies of scale (see 4 section II).

In this setting, countries could integrate the global supply chain to benefit from the gains from trade and other benefits of globalisation (mostly technical spillovers and product diversity) while using the regional scale to experiment diversification. Regional units are likely to be less

26. The logic, straightforward when considering exhaustible resources, is not so different when considering labour. Remember that in Fisher (1906), instruments of wealth that are qualitatively different (a fertile field against a less fertile one) are considered to be of different nature. Conversely, if instead of assuming that labour is commensurable in terms of qualification (the idea that a labourer can become an engineer under the optimal system of relative prices) imperfect if not un-substitutability was assumed, adequate policies for labour management should be revisited.

27. Including safe assets such as government bonds.

prone to market inefficiencies, while increasing voice and accountability, making those the ideal receptacles for economic experiment. Still, the country level is needed to coordinate regional units while monitoring the evolution of overall specialisation. A final critical role for country level institutions is to organise interactions between agents organising the global supply chain (first and foremost multinational firms) and regional endowments. A fine balance must be found between resources devoted to local experiments and instruments forming the comparative advantage at the disposal of the global supply chain (Costinot et al. 2012).

In this final respect, subsidiarity finally links with substitutability in money-value. Substitutability is usually considered in the literature in line with absolute scarcity concerns. Greater emphasis should be put (at least in the short/medium term) on geographical substitutability, investigating who should decide to which end a given instrument of wealth should be used.²⁸ Should the rules associated with market mechanisms and perfect substitutability/fungibility²⁹ still be used in our framework?

In our view the question of substitutability/fungibility cannot be detached from the issues surrounding the concept of liquidity. Issues regarding substitutability/fungibility do not invalidate Fisher's theory of capital, but they do raise questions regarding the theory of value used in association. The core issue behind substitutability/fungibility is therefore the question of liquidity between markets trading in incommensurable instruments of wealth. Uncertainty imposes a trade-off between liquidity and precaution, which is nothing else than risk in financial terms. Reducing risk according to the precautionary principle would involve the reduction of money-value substitutability via money, degrading money as the epitome liquid instrument. This may sound like a radical step, but markets already have ways to degrade substitutability between financial instruments. Making provisions for uncertainty does not necessarily require a complete redesign of markets, but it certainly requires to reinvestigate the role of money.

In the end, Neumayer (2010) is right to focus on the issue of substitutability. We would only insist on substitutability to be understood in its broadest meaning of substitutability/fungibility. Exploring this idea led us to conclude that the role of money in trade should be revisited, an idea familiar to the careful reader of Keynes (see the analysis in Maurin (2013)). This idea will also come as no surprise to specialists of the study of international dis-equilibria and the role of financial flows in international debt and exchange rate crisis. The study of open economy sustainability should be extended in that direction to provide a firmer theoretical foundation for the notion of "virtual sustainability". Investigating the factor content of trade flows and

28. And therefore in our framework at which level, regional or country level?

29. We propose to use the concept of substitutability to refer to issues regarding substitution between two qualitatively (and probably incommensurable) instruments of wealth, while saving fungibility to indicate potential geographical substitution, between the regional and country management.

substitutability amongst traded instruments of wealth will inevitably lead to questioning the free flow of financial assets that are the counterparts of those real flows.

Back on the real side of the balance of payments, taking into account those elements would create along sustainability lines a set of tradable and non-tradable instruments of wealth. We saw that the limit can be set by transaction costs (Dornbusch et al. 1977) but the literature provides other explanations such as the lack of factor price equalisation in an HO model. More recent attempts also include the Melitz (2003) model where the decision to export is based on firm productivity. Taking a sustainability perspective would add another motive to separate industries producing tradables and non-tradables, between country-level exports and regional-level sustainability.

The global supply chain is based on the exploitation of the international division of production processes. Exploiting countries' comparative advantages, the global supply chain organises production at the world level, providing opportunities for individuals and firms in more countries than ever before to get involved into global production (Friedman 2005). But there is no institutional framework comparable to the state level framework to regulate this global layer of production. A firm should be regulated at the adequate level in terms of institutions and wealth mobilised. If the counterfactual prevails, the risk is generalised free-riding, imperfect enforcement and internationalisation of externalities (Ostrom 1990). This violation of the subsidiarity principle creates a basis in our theory of sustainability and trade for the expansion of the scope of non-tradable goods.

This finding is in line with the observations made for example by Schneider et al. (2010) and could give a basis in sustainability theory for the “de-globalisation” of part of the global supply chain. The risk here would be to go to far, forgetting that there are powerful income gains from trade attached to the global supply chain, as long as it is organised in line with comparative advantages. The considerable work at hand is therefore two-fold. At the global level, institutions should be created to regulate the global supply-chain, implying a “scaling-up” of some responsibilities. At the regional level, more room for instruments of wealth management should be given at the scale best suited to manage sustainable those instruments. In the biggest countries more regional power might imply to “scale-down” some responsibilities and introduce an amount of political and economic decentralisation.

Under this organisation, consistency could be restored in our sustainability framework. This organisation is clearly a second best compared to the creation of an integrated world economy. It might nonetheless be the only workable option between the status-quo and an integrated world economy that might not properly consider sustainability issues. Our current organisation seems closer to the country perspective, with little scope for convergence towards the first best

of global integration. In this context, the use of policy instruments to protect conjecturally threatened³⁰ instruments of wealth seems warranted by the precautionary and the subsidiarity principle.

Safeguard measures will be needed in an open economy sustainability strategy, as a second best for the institutions missing. Those measures will be crucial not so much during the development of industries according to comparative advantages, but much more during the transition towards diversification when traditional advantages fade. Safeguard measures could then help countries to go upmarket without running the risk of depleting instruments of wealth which would effectively “pay” for the transition. They could also be warranted in sectors plagued by externalities when complete internalisation is not possible.

Safeguard measures would lead to a decline in size of the global supply chain and a re-localisation of part of the global production process. This phenomenon seems to us inevitable. Rising energy costs, competition between factors and social unrest are already pushing for re-localisation. The move is made more important by traditional agglomeration forces. The hopefully compelling case we made for a consistent organisation under the subsidiarity principle would only exacerbate those trends. An interesting question would be to compare the size of the global supply chain under several scenarios regarding externalities, money-value substitutability and level/organisation of institutions for inclusiveness.

It would then be possible to assess how far the world economy is from sustainable integration and in need of our proposed second best. This logic is in our view implicit behind the debate about responsibility for depletion. Multi-Regional Input-Output analyses offer important insight into how resources are actually extracted, traded, and consumed. The idea of “virtual sustainability” expresses the shallow nature of a sustainability based on the depletion of resources elsewhere. It also stresses the danger of depending on exports of exhaustible resources in development. Oleson (2011) already questioned the dependence of countries on imported resources as a potential violation of the social contract between the government and its citizens.

A final note should be made regarding indicators of sustainability. Adjusted Net Savings (ANS) stand as the prominent indicator of sustainability being forward looking and grounded in theory. Under the assumption of the inter-temporal model used as a foundation for ANS it is a predictor of future sustainability. The literature on open economy sustainability already included suggestions to amend ANS for capital gains which would correct the indicator for the long run impact of trade. Considering our previous objections, it is clear that ANS should also be amended for a measure of the opportunity cost of specialisation, to reflect the potential future

30. We are referring here to both over and under-exploitation of some instruments of wealth.

cost of diversification and its drag on the country's wealth. A measure of the cost associated with an unsustainable institutional organisation should also be included. We explore those points in chapters [3](#) and [4](#).

Conclusion

Those observations conclude this chapter on trade and sustainability. This long journey started with the review of the models and results in the literature on trade and the environment. The environment has been incorporated into prominent trade frameworks, most notably the HO model. This was a natural starting point for exploring sustainability and international trade driven by factor endowments as well as how key trade theorems relate to the environment. The lasting contribution of the field is doubtlessly the decomposition of trade impacts on the environment depending on the composition, technique and scale effects. The decomposition is especially helpful when assessing the likely consequences of trade liberalisation on polluting emissions. This literature, based on trade models, offers a global outlook on environmental issues setting the conditions for optimal pollution at the international level.

A different perspective is presented in the literature on open economy sustainability, focusing on country by country sustainability in an open context. Openness bring challenges for instruments of wealth management, natural resources especially. Exogenous world prices create capital gains from trade, as the value of natural resources can be expected to increase over time. Investing those gains sustainably and adopting the right savings policy is then critical to sustainability. Authors in this literature naturally orientated themselves towards institutional and property rights issues, of prime importance when considering sustainable reinvestment policies.

The models developed to assess responsibility for depletion corroborate those findings, stressing that a large share of natural resources depletion in resources rich economies is undertaken for exports. This makes the timing of trade liberalisation critical, as incentives to specialise may trap natural resources rich economies into an unsustainable specialisation. Should such a specialisation emerge, trade policy instruments are warranted to avoid over-exploitation of natural resources. Those very rich and versatile contributions to the understanding of the links between international trade and sustainability should be mobilised to propose a framework for sustainability in open economies. We believe that the pieces of this puzzle are already there, they are just scattered across different fields in the literature.

We defined sustainability in chapter 1 as the need to maintain comprehensive wealth over time, maintain constant value-consumption over time, control for money-value substitutability to be consistent with physical substitutability while guaranteeing inter and intragenerational equity. International trade brings a fundamental challenge to this vision of sustainability as international trade is born out of the imperfect organisation of the world, between full integration and complete country level autarky. International trade creates exchanges of goods and investment flows between countries, altering domestic development paths without global

institutions to control for sustainability.

Faced with this “grey area” for sustainability, we can not maintain consistency by just scaling-up at the world level the within-country optimal organisation. The decision to open to trade alters the optimal development path while increasing the specialisation of the domestic economy in line with world level relative preferences. Still, the application of the subsidiarity principle is valid as an instrument to minimize uncertainty in the development path while setting and preserving inclusive institutions, accountability and voice for all agents. Subsidiarity allows for a better match between physical and money-value substitutability via a better accounting of local preferences. This idea needs to be extended in the open economy context.

We propose to consider the concept of fungibility to describe the need to take into account not only physical substitutability but geographic substitutability. Regions should be allowed to preserve a greater diversity in instruments of wealth than would be commended by international incentives to specialise, as a way to hedge against uncertainty and foster structural change. Only by controlling both physical and spatial substitutability (substitutability and fungibility) is it possible to take advantage of the gains from trade (productivity and specialisation gains) without compromising the needed future diversification of the economy. This observation is the basis for a dissociation between the country contribution to the global supply chain, guided by comparative advantages and specialisation, and a regionally sustainable organisation of instruments, aiming for symmetry in use, diversification and equity.

In this perspective, factors limiting perfect substitutability are not necessarily bad. Some existing rigidities such as cultural preferences and transaction costs can play for sustainability by limiting resources depletion. In situations of increasing asymmetry in the distribution of instruments of wealth, countries should be allowed to use trade policy instruments to reduce the use of some instruments of wealth while encouraging the use of others. Asymmetry should be reduced in terms of comprehensive wealth, but also in terms of spatial distribution of wealth instruments.

This conceptual framework sets a clear research agenda while leaving us with many questions. What is the actual size of the regions? How to draw the line between domestic diversified production and global specialisation? What should be the role of policy makers? How to use financial counterparts of trade flows in case of unbalanced trade? Those many questions (to which many can be added) can only be answered once the potential impact of the agents involved, their potential role for sustainability is better understood.

We stressed how the combination of present value, current value indicators, counterfactual studies and scenarios could form the basis for sustainability assessment and guide policy

makers. As the leading current value indicator of sustainability, Adjusted Net Savings should be the cornerstone of sustainability assessment (see chapter 4 section III for an application). Nonetheless, the indicator needs to be amended for the constraints on the optimal development path brought by international trade to be used in an open economy context. Present value indicators needs to amended only if they interact with a component of the global supply chain.

As a first contribution to this agenda, we propose in the next chapter to investigate the impact of international trade on the use of wealth instruments. Using a dynamic HO model, we can consider factor usage along the development path, comparing wealth and consumption in autarky and free trade under several sustainability scenarios. This model also addresses the problem of convergence in consumption and income under different configurations in world prices and the resulting steady-state levels. In chapter 4 we focus on the insertion of resources rich countries in the global supply chain, often characterised by the well-known resource curse. We show, using a counterfactual exercise, that sustainability rules are regularly violated in resources rich countries and stress the correlation between this finding and an HO pattern of trade. We conclude, using the [Ethier \(1982\)](#) model that resources rich countries should turn to a more intra-industry pattern of trade to avoid being stuck in the middle income trap, providing further evidence that trade plays a major role in sustainability and the “switch” to diversification.

CHAPTER 3

International trade and structural change: a dynamic model of weak sustainability

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Introduction

IN the previous section we presented the impact of trade on our definition of sustainability. We stressed the need for a comprehensive approach for trade and sustainability. Most of the literature, starting with the Copeland and Taylor (1994) model, concludes that trade has a positive impact on sustainability and/or the environment. International trade makes resources allocation more efficient as countries specialise according to their comparative advantage. International trade also alters domestic prices when opening-up to free trade. World prices reflect world demand for resources. Depending on the domestic distribution of endowments relative to the world distribution, instruments of wealth will see their price increase or fall. Countries relatively well endowed in natural resources can expect capital gains from international trade, as higher global demand pushes domestic prices up.

The “open economy sustainability” literature focused on the time dimension and the capital gains. Early articles by Asheim (1986) and more recent publications by Vincent et al. (1997) and Pezzey (2004) suggest that opening up to trade and then being subject to the forces of international trade could have a major impact on country level sustainability strategies. As capital gains generate resource windfalls for the domestic economy, resources rich countries are expected to use the extra income in a sustainable manner. The Hartwick (1977) rule promotes sustainable reinvestment of the rent into produced capital to maintain wealth and consumption as exhaustible resources are depleted.

Responsibility for sustainability falls mostly on domestic management. Implicit in this argument is the notion that under free trade, trade partners will converge in levels of comprehensive wealth, income and consumption per capita. This may not be the case depending on the original situation of the country (Atkeson and Kehoe 2000). Trade liberalisation should be undertaken considering the situation of future partners, their relative distribution of endowments. Trade induces several evolutions for individual countries and is one of the key determinants of a successful development strategy. Early specialisation in line with comparative advantages must pave the way for some diversification in order to go upmarket and pursue development beyond the middle income trap. This is the problem of structural change.

As the current questions surrounding sustainability in China suggest, there is no easy answer with respect to how structural change is supposed to happen without impeding the standard engines of growth based on comparative advantages. Some favour a rebalancing towards internal demand and investment, while others stress the inflation risk, which could wipe out a large part of the previous gains from trade. Structural change is in essence a gradual evolution in the composition of the economy. Any “trade-induced composition effect” is based on the

assumption that the domestic economy can reallocate factors to booming sectors. The domestic economy should also be able to substitute instrument of wealth for one another. Analysis of trade-induced composition effects in international trade are therefore based on the assumption of perfect money-value substitutability.

Countries willing to enter international trade should consider the timing and the opportunity to adjust their distribution of instrument of wealth to the needs of the trading system. We saw in the previous chapter the importance of maintaining comprehensive wealth as a whole as much as maintaining diversity in the instruments composing it. Without similar levels of comprehensive wealth, it is unlikely that trading partners can obtain symmetric gains from trade or converge in levels of consumption per capita. A successful insertion in international trade rests on both comparative advantages and the ability to adapt the composition of domestic wealth to the changing reality of international exchanges.

Those observations are to be put in the context of the violation of some assumptions associated with standard trade theory, the most famous one being the factor price equalisation (FPE) condition in HO models. The robustness of the results regarding convergence in trade models when the FPE condition is violated has periodically come under scrutiny (Cuñat and Maffezzoli 2004, Ventura 1997). Differences in technology and productivity are usually put forward to explain the poor empirical performance of HO models (Trefler 1993). The explanation is seducing and is doubtlessly a major part of the story. Still, the development of comprehensive wealth accounts, accounting for the value of natural capital, human capital and institutions, gives some renewed credit to the classic explanation for FPE violations: major discrepancies in factor endowments.

Table 3.3 and appendix D show the ventilation of produced capital, human capital¹, renewable and non-renewable exhaustible resources. Debaere and Demiroglu (2003) studied the likelihood of factor price equalisation in the world economy and conclude it is systematically violated between developed and developing countries (see section III.2). Differences in factor prices is therefore the norm and not the exception in international trade. This is likely to upset many conclusions on the impact of international trade on sustainability. If natural resources are priced differently depending on the distribution of endowments in all the potential trading partners, it is possible that trade liberalisation is not always beneficial. Trade liberalisation may be profitable when higher world prices can be expected. But this benefit can be offset by

1. A presentation of the method used by the World Bank to obtain the three basic components is available in chapter 1 section I.2. Intangible capital is then broken down using the estimates from the World Bank (2006), where human capital is on average 36% of total intangible capital across countries in 2000. Those results using an average are therefore to be taken more as medium values of an interval of trust than robust approximations. see section III.2 for more details

larger fall in other factors income, conditional to the prevailing trade setting. As a consequence, world convergence in the distribution of instruments of wealth can no longer be expected, even in the long run. Countries may react to trade liberalisation by further increasing their comparative advantage to increase the resource windfall. Alternatively, they may hasten reinvestment in produced capital as trade liberalisation reduces overall income and wealth.

If trade is to foster sustainability, management of the productive base in a given country should be undertaken under valid assumptions regarding the trade position. The generalised Hartwick rule (Asheim et al. 2003), the basic rule to orientate investment and reinvestment, should be modified to consider its impact on the distribution of endowments. The Hartwick rule may create a tension in the context of structural change. There can be an incentive to invest in factors that are not the factors on which future prosperity is based, but factors that are cheap relative to the rest of the world and the basis of the comparative advantages. We term the policy of following the general orientation of the Hartwick rule structural change (SC) as it leads countries to substitute for natural capital, building a renewable productive base centred on produced capital. The alternative would be to focus on the enhancement and maintenance of the endowments sources of the comparative advantage. We term this policy the comparative advantage (CA) strategy.

The literature beforehand focused on the time dimension and the capital gains. We believe the CA versus SC debate is more important in terms of sustainability as it has lasting impacts on the structure of the economies. It is also relevant to the controversy about weak and strong substitutability. If comparative advantages rest on one particular instrument of wealth or factor endowment, then the management of this instrument becomes critical even under perfect substitutability. In this chapter we investigate how the need for structural change may impact countries depending on the nature of trade and relative factor endowments. We hope to shed some light on the relationship between wealth, consumption and specialisation and define sustainable paths. In this context, the need for a consistent long run path (Heal 1998) must be balanced with short run imperatives regarding income gains from trade and short-run rigidities. This arbitrage could lead countries to favour depletion of critical natural capital to gather income gains, destroying in the process both their current comparative advantages and the possibility to build new ones.

We propose to study the investment/consumption behaviour of a representative agent in a 2 countries, 5 goods, 4 factors HO model. We study the behaviour of the representative agent following both SC and CA strategies. Within those two investment strategies we consider the possibility of trade under FPE (the integrated equilibrium (IE)) or without it (the complete specialisation equilibrium (CS)). The model is based on Cuñat and Maffezzoli (2004) who elab-

orated the original 2 countries, 3 goods 2 factors version. This model follows the early work of Ventura (1997). This modelling strategy unites three fields: weak sustainability (perfect money-value substitutability), Heckscher-Ohlin theory of trade and neoclassical growth. Although this strategy imposes some strong restrictions on the dynamic optimisation process, it yields interesting insights on the arbitrage between consumption and investment in different trade settings.

We first show how international trade can reduce consumption and wealth in both countries. Both countries need to alter the relative intensity of their autarkic production to produced goods that are intensive in either labour and produced capital or exhaustible resources. As a result, extra coordination costs occur under free trade and steady-states level of consumption and wealth are lower. This result is unusual. Still, we believe it illustrates an important dilemma for sustainability. In autarky, the best possible use of instruments is simply to use all the instruments available to maximise production. After trade liberalisation, countries have to find a source of comparative advantage, to produce goods that might be exchanged with their partners. Hence, our modelling strategy allows us to show this dilemma of diversification versus specialisation in international trade.

We then show how consumption and wealth are reduced by an increased asymmetry in the distribution of endowments. Asymmetry in endowments is defined as the spread between one country's endowment in produced capital and labour on the one hand and exhaustible resources on the other hand. As a consequence, countries have an incentive to reduce asymmetry through the adequate investment strategy. Both countries systematically loose out entering international trade. Still, they may be interested in entering international trade in situations of high asymmetry. Under free trade, the cost of structural change from high to low asymmetry is lower than in autarky. Trade grants access to instruments of wealth scarce in the domestic economy but abundant in the trading partner. As a result, factor prices increase less rapidly with scarcity under free trade than in autarky and countries may reduce asymmetry at a quicker pace.

Our comparison of the trade settings reveals an asymmetry in the incentives to open-up to trade. The country intensive in exhaustible resources will favour free trade when asymmetry is high but not when asymmetry is low. On the contrary, the country intensive in produced capital and labour will try to preserve free trade (once enforced) under any level of asymmetry as a reversal to autarky would leave it *relatively* worse-off. This feature comes from the dynamics of accumulation where renewable exhaustible resources yield a bonus every period, whereas produced capital depreciates. Another consequence of this is the fact that regardless of the investment strategy followed (CA or SC) the country relatively well endowed in exhaustible

resources has no incentives to enter international trade when asymmetry is low.

We finally investigate some scenarios, to assess the consequences of country-specific shocks on our constrained steady-states equilibria. We stress how the introduction of free trade allows idiosyncratic shocks to reverberates in both countries. We call this property the “burden sharing” capability of international trade. More originally, we show how the trade setting has an impact on which countries bears the greatest consequences from the shock. When factor prices are equalised, the adjustment is stronger in the country where the shock did not take place. The opposite is true under complete specialisation. In this respect, factor price equalisation certainly creates co-responsibility in the trading system and requires a global management of idiosyncratic shocks on different instruments of wealth.

Our results have many implications for both sustainability and international trade. We believe our results provide a theoretical rationale for the computation of “virtual sustainability” (Atkinson et al. 2012). As different distributions of endowments lead to different options regarding trade liberalisation, monitoring of the factor content of trade is necessary to avoid excessive trade-induced depletion of natural resources. This observation lead to our proposal to amend Adjusted Net Savings (ANS) to take into account the impact of international trade on reinvestment strategies. The savings from trade when going from low to high asymmetry should be added to ANS when they are saved to be reinvested. They should be subtracted if they are consumed or invested abroad. Our results also stress how asymmetry in the distribution of *all* instruments should be considered when setting trade relations. As a consequence, asymmetry is an indicator of the opportunity of economic integration as in the Balassa (1961) scale. Following those two findings, we believe our result legitimise the use of trade management instruments to a) collect the extra savings required because of international trade and b) foster regional integration in line with sustainability and the subsidiarity principle.

This chapter is structured as follows. In section I we review the literature on dynamic models of trade and justify our modelling strategy. In section II we present the model, notably the important assumptions on the production system. We also demonstrate how the separation of the price setting mechanism from the dynamic model allows us to test several trade settings. In section III we present the simulations under all the scenarios and cases. In section IV we interpret the results before concluding.

I Literature review

When assessing the impact of trade on natural capital, attention is usually drawn to the works of Copeland and Taylor (Copeland and Taylor 1995, Antweiler et al. 2001). The decomposition of the impact of trade into scale, technique and composition effects is a powerful way to discriminate between the contradictory impacts of international trade on the environment. However, the Copeland and Taylor approach is limited as it is essentially static. Also, by focusing on pollution to represent the environment, it emphasises the role of environmental regulation over the role of direct availability of natural resources in the production process. Therefore, a complementary approach with an emphasis on resources over pollution is required.

Resources have been studied before pollution in trade settings. The framework presented in Dasgupta and Heal (1979) and Dixit and Norman (1980) set the norm for the study of resources in international economics still in use in many models today. Resources analysis in open economies is based on standard results in trade theory. To be able to use trade theory to offer predictions on resources prices in an open economy setting, trade theorems and results must stay valid under relatively loose assumptions. Deardorff (1980) undertook to generalise a formalisation of the average gains from trade. The results are extended in a later contribution to account for trade distortions (Deardorff 1994b).

Some uncertainty remained on the generalisation of the theorems associated with the Heckscher-Ohlin (HO) model. One of the most obvious violations of the Heckscher-Ohlin, Stolper-Samuelson and Rybczynski theorems was the lack of worldwide factor price equalisation (FPE). FPE is much debated in trade theory as it is a key condition behind many results. Still, as Baldwin (2008) reminds us, Ohlin himself didn't believe FPE to be a realistic precondition for trade analysis. Deardorff (1979) shows that the chain ranking of comparative advantage established by Vanek (1968) holds when FPE is not verified if either impediments to free trade or intermediate goods are introduced. The chain prediction breaks down if both modifications are involved. Trefler (1993) investigates a weak version of FPE to allow for productivity differences between countries and finds a significant predictive power to the HO model.

Interrogating the validity of the HO theorem, Deardorff (1982) shows that it holds regardless of FPE or tariffs and export taxes in the absence of transportation costs. The factor content version of the HO theorem is generalised by showing the negative correlation between autarky prices and the factor content of trade. Discussing FPE again, Deardorff (1994b) stresses the usefulness of the concept of the "integrated world economy" from Dixit and Norman (1980). The integrated world economy concept bears similarities with Samuelson's "Angel parable" (Samuelson 1949). The possibility of FPE is assessed based on the comparison between the

factor endowment lens and the factor use lens. If the factor endowment lens passes outside the factor use lens, FPE will not occur. FPE will break down if the asymmetry in the distribution of factor endowments across countries becomes “excessive”.

An empirical test based on this prediction conducted by [Debaere and Demiroglu \(2003\)](#) shows that the dissimilarity of endowments is too high for FPE to occur at the global scale, but can occur between OECD countries. [Bernhofen \(2009\)](#) explores this case, extending the test of [Helpman \(1984\)](#), based on the absence of trade costs, similar technology across countries and diversity of endowments incompatible with FPE. He shows how, as endowments determine a given cone of diversification, countries can not produce goods requiring factor intensities outside of this cone efficiently. In a n country world, this means that predictions about factor flows need information about factor distribution in *all* the trading partners, not only the considered pair. Information from all the cones of diversification needs to be considered.

The breakdown of factor price equalisation creates multiple cones in a Lerner-Pearce diagram, and the possibility that the “integrated world economy” turns into a place of separate cones of complete specialisation based on relative world endowments. Exploring the breakdown of FPE yields interesting insights about the factor content of trade. For example, [Umanskaya and Barbier \(2008\)](#) explore the pollution heaven hypothesis while relaxing the FPE condition. Without FPE they show that the rich country is a potential pollution haven under some conditions for the endogenous environmental policy.

A second important step would be to analyse the standard four theorems in a dynamic context. We conducted a simple assessment of those theorems in chapter 2 section III. A country relatively well-endowed in an exhaustible resource opens-up to trade. In a two countries setting, this would result in an increased use of the exhaustible resource as the price falls. Following the Hotelling rule, a lower resource price reduces the rent and the incentive to extract. Conversely, consider a resource boom resulting in an increased supply at lower prices. Following the [Rybczynski \(1955\)](#) effect this would have a more than proportional effect on specialisation which could feed lasting higher depletion. The key to distinguish between those two potential effects is to consider the dynamics between the endowments in the considered country.

The analysis of the dynamic properties of trade is somewhat tricky in the context of traditional trade models. Accumulation (or productivity) dynamics can lead to a change in the position of a given country relative to its trade partners. A large body in the literature investigates dynamic comparative advantages in various contexts. [Krugman \(1987\)](#) examines the consequences of a dynamic comparative advantage based on learning-by-doing in the context of the resource curse. The impact of dynamic advantages on innovation are presented in [Grossman and Helpman \(1991\)](#). In HO theory, factor accumulation may lead to a reversal in the compar-

ative advantage for the considered country, as a previously scarce factor is accumulated. Factor intensity reversal confuses the prediction of the gains from trade and is generally avoided.

Stiglitz (1970) tested the three theorems of the HO approach and the resilience of FPE in a dynamic context. He concludes that the pattern of trade depends on the decision by trading countries to specialise or not, either in the labour or the capital intensive good. Differentials in pure rate of time preference will also make a difference. A similar point is made by Bogmans and Withagen (2010) who construct a dynamic HO model to investigate pollution haven formation in a dynamic context. They explore the conditions for complete specialisation in the dirty good, pinning down cases under which it may happen in either country.

From a sustainability perspective, the HO approach in international trade is quite appealing. As international trade is explained by factor endowments, the link is easy to do with the capital theoretic approach in sustainability. Factor endowments of the H-O model are capital stocks of the sustainability literature. Arrow et al. (2010) proposes to distinguish between 5 different types of capital: health, human, produced, natural and social capital. Although it can be empirically valid and important to distinguish between several different capitals, from a theoretical perspective, it matters only to distinguish between capitals which accumulation patterns are different.

Early dynamic models of sustainability focused on non-renewable exhaustible resources. Dasgupta et al. (1978) present a dynamic model with the possibility of foreign investment. After the Hartwick (1977) rule generalised by Dixit et al. (1980), Asheim (1986) put the contribution of trade to sustainability rules in perspective by introducing the concept of capital gains. Based on exogenous prices, capital gains demand amendments to the standard Hartwick rule (see chapter 2). Hartwick (1995) explores the consequences of endogenous world prices. Vincent et al. (1997), Hamilton et al. (1998) and Pezzey (2004) present a rigorous treatment of capital gains as productivity gains.

Brander and Taylor (1998) present a model based on a renewable exhaustible resource with open access as in Chichilnisky (1994). They confirm Chichilnisky's static results as the resource exporter experience a significant decline in steady-state utility. An all important article by Van der Ploeg (2010) summarises the impact of openness on sustainability when overseas investment of rents is possible and trade is treated as a time dependent productivity improving variable. He concludes that trade provides a rationale for domestic underinvestment of the rent (hence negative adjusted net savings) as it is more rewarding to invest rents abroad instead. This corroborates the empirical results of Rubio (2004) and is consistent with the conclusion of the model of Okumura and Cai (2007) based on factor complementarity. The authors show how, when factor endowments are complementary inputs, it makes sense to turn domestic assets into

foreign ones and enjoy the income flows from abroad.

Empirical exercise based on input/output tables bring confirmation of those theoretical results in terms of factor content of trade. Proops et al. (1999) and Atkinson and Hamilton (2002) quantify the amount of natural resources embodied in trade flows. Atkinson et al. (2012) expand those early results on a wider sample of countries and find increasing imbalances (see chapter 2). Despite those results, the emphasis put on capital gains resulted in reduced academic interest for the overall impact of international trade on sustainability. The best way to account for the impact of trade seemed to be to set domestic and international prices at the optimal level, matching market prices with shadow prices. As advocated by Van Der Ploeg (2011) efforts should be directed towards institutional improvements.

Still, our review of international trade and sustainability in chapter 2 suggests it is worth investigating trade mechanisms further. Based on the contributions of Solow (1974) and Hartwick (1977) sustainability characterises development paths, beyond the standard imperatives of income gains and growth in output per capita. As presented in chapter 1 sustainability interrogates the nature of development and its intensity in resources and endowments. In ?, it is shown that many countries have grown by substituting produced capital for natural capital.

Structural change usually goes hand in hand with sustainable development as demand switch from natural capital intensive goods to more human capital intensive ones. This point is made by López et al. (2007). The exhaustible resources dynamics of structural change are studied in Faber and Proops (1993). The Hartwick rule and structural changes are two sides of the same coin. Substitution of produced capital for natural capital is obtained via the Hartwick rule and structural change happens by substituting produced capital for natural capital. Nevertheless, the two are not synonyms. Any amount of substitution for natural capital is structural change, but only the reinvestment of all depleted natural capital can potentially qualify as following the Hartwick rule.

The literature on structural change considered the critical role of trade in influencing if not setting reinvestment policies. The core of the analysis is the balance between domestic and foreign incentives for depletion and the use of the different components of wealth. Chichilnisky (1993) investigates the impact of property rights on the composition of production when an open access renewable resource is involved. Klepper and Stähler (1998) stress that unilateral sustainability policies with competitive world prices may lead to income gains without sustainability. As in Okumura and Cai (2007), countries import sustainability from their partners. Redding (1999) touches at the core of the structural change versus comparative advantage argument, investigating how a developing country can diversify away from its comparative advantage. He presents a model of endogenous growth where comparative advantages can be build out of the

large productivity growth potential. He concludes that in this setting, Ricardian trade might be welfare reducing and state intervention is desirable.

The links between trade and structural change are explored at regular intervals but do not seem to come under intense scrutiny. We believe the study of open economy sustainability makes the case for putting structural change again at the core of trade studies and policy design, in order to improve the management of the instruments of wealth. Developments in dynamic macroeconomic model could certainly help to model realistic dynamics compatible with endowments-based trade models. Since [Arrow and Debreu \(1954\)](#) macroeconomic models study growth and factor accumulation. The Lucas critique and the development of rational expectations opened the field to a class of perfect foresight deterministic models ([Stokey et al. 1989](#)) used to study economic dynamics.

A large part of the “rational expectation revolution” was devoted to endogenous growth models and innovation ([Aghion and Howitt 1998](#)) but many kept using deterministic models applied to dynamic problems. A seminal article in this field is [Ventura \(1997\)](#). The author endeavours to explain the higher growth rate in developing countries combining a Ramsey growth model with an HO model. Although his results are based on exogenous cross-country differences in labour productivity, he demonstrates how the very Rybczinsky effect we discussed above can offset the tendency of produced capital return to decline with accumulation (through increased demand of the capital intensive good). Trade is here the mechanism behind quicker capital accumulation in southern countries, fostering structural change and convergence in income.

The Ventura model is explored further by [Atkeson and Kehoe \(2000\)](#), searching for factors affecting the rate of convergence. They find the distinction between early and late bloomers to be relevant, late bloomer ending with a lower level of steady state income than early bloomers. [Eliasson and Turnovsky \(2004\)](#) explore the dynamics of a renewable resource in an endogenous growth framework. They find the renewable resource sector to reach a constant steady state size while the rest of the economy keeps growing. [Cuñat and Maffezzoli \(2004\)](#) examine the consequence of FPE breakdown on convergence. They find that the lack of FPE prevents income convergence in per capita produced capital. This result is confirmed by [Bajona and Kehoe \(2010\)](#) who investigate under which conditions opening-up to trade causes either divergence or convergence. They stress the importance of the elasticity of substitution between traded goods in determining the outcome. Critical to our object, they show that FPE in one period does not guarantee FPE in other periods.

Other articles relevant to this discussion involve [Deardorff \(2001\)](#), [Cheviakov and Hartwick \(2009\)](#) and [Bazhanov \(2010\)](#). [Deardorff \(2001\)](#) presents how behaviours derived from the neo-

classical growth model can explain empirical regularities in international trade. In line with his previous works he shows how the breakdown of FPE yields diversification cones and resulting discrepancies in steady state income levels. [Cheviakov and Hartwick \(2009\)](#) provide a stress test of the rate of decay associated with produced capital in the context of exogenous technical change as in the Solow model. They confirm that a high rate of decay is associated with economic collapse, so that high enough technical progress is required to maintain economic activity. [Bazhanov \(2010\)](#), also using a DHSS model, takes issue with the compatibility of initial conditions with a desirable per capita consumption path. He offers leads to transition from an unsustainable initial state to a state consistent with sustainable steady state consumption.

Those mostly theoretical models are designed to address salient empirical regularities or to test scenarios. Efforts to provide such tests usually involve computable general equilibrium models (CGEM). [Bailey and Clarke \(2000\)](#) conducted an assessment of sustainability in an open economy context with predictions running to 2050. They test for lower technical change and lack of backstop technology, still finding the world to be sustainable as a whole. Another example is the model developed by [Turner et al. \(2011\)](#) concluding that non-sustainable carbon emission in Wales are concentrated in exporting industries. A similar distinction around the responsibility for depletion is at the core a recent works on “virtual sustainability” ([Atkinson et al. 2012](#)).

Our review of the three fields of international trade theory, neoclassical growth models and sustainability in chapter 2 presented the common tools and models developed to build bridges between the fields. The shorter presentation of the literature in this section exposed the common underlying concepts in international trade and sustainability. In HO models, factor price equalisation (FPE) is determined by asymmetry in endowments. A breakdown of FPE generates multiple cones of diversification, *de facto* reinforcing specialisation. As a result, in both international trade and sustainability theory, asymmetry in endowments is therefore a key driver of specialisation and a potential impediment to structural change.

The second conceptual common point is the notion of convergence. Convergence in income and comprehensive wealth is important in the definition of sustainability we proposed in chapter 1. Although technically constant consumption over time does not imply the steady state level to be similar across countries, this position would be incompatible with intragenerational equity at the country level. The question of convergence in income is also associated with wealth management, as convergence in income convey a message about the structure and the return on domestic wealth. The possibility of convergence towards the steady-state is therefore critical to predict trade patterns and set fair factor rewards and goods prices.

Similarly, if convergence depends on substitutability between traded goods in an HO model,

it implies that it depends also on substitutability between factors. As stressed by Neumayer (2010), substitutability in production is key to sustainability, while the literature suggests that substitutability in preferences is also important. Convergence is therefore critical for both sustainability (via its impact on intergenerational and intragenerational equity) and international trade in a dynamic setting (via its impact on specialisation).

Those elements lead us to build a dynamic model with perfect money-value substitutability to assess the impact of HO trade on convergence and asymmetry in endowments. As convergence and asymmetry are the two critical theoretical dimensions of sustainability in an open setting we will investigate two different possibilities. First, we will examine a world where both countries accumulate the same endogenous instrument of wealth, as in situations of structural change when this instrument is produced capital. We term this scenario SC for Structural Change. We then investigate the scenario under which countries focus on the instrument of wealth constituting the source of their comparative advantage, so that different instruments are accumulated in different countries. We term this scenario CA for Comparative Advantage.

We will compare the evolution of consumption and wealth in the CA and SC scenarios under two different trade settings: an integrated equilibrium for the world economy (IE) and lack of factor price equalisation leading to cones of complete specialisation (CS). To this end, we build a computable general equilibrium model to test several scenarios related to capital accumulation and resources depletion. Our framework allow us to examine the conditions of convergence in international factor prices, producing some results regarding initial and steady-state position of our trading countries. In the next section we present the model, composed of two components: a static trade model (section II.1) and a dynamic model with four factors (section II.2).

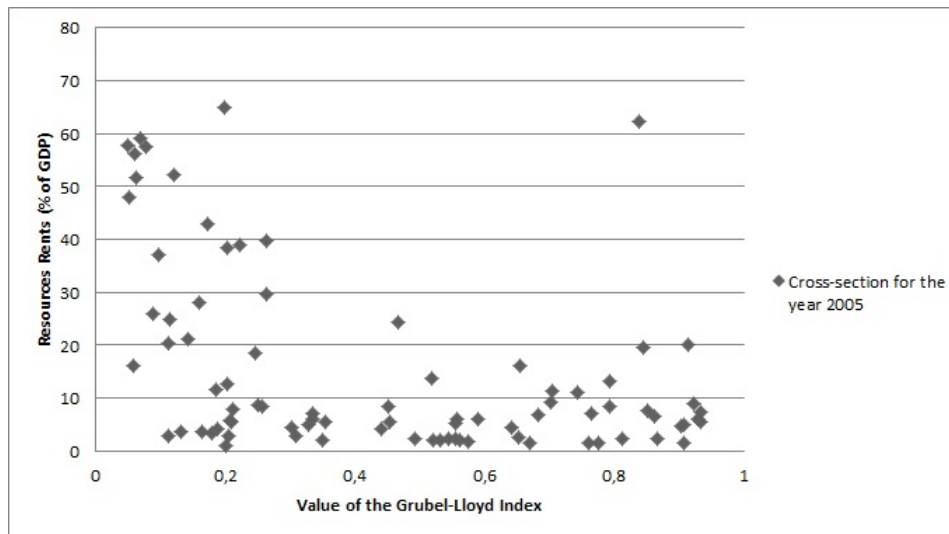
II The model

We build on Cuñat and Maffezzoli (2004) to propose a “generalised” model of neoclassical growth. The model is based on the articulation of two components:

The static trade model: at the beginning of every period the static trade model is used to calculate the new factor prices and factor price ratios from the international trade production equilibrium.

The dynamic model: period prices and price ratios are then inserted into the dynamic model. The dynamic model computes the new stocks of capital that will be used in the subsequent periods to obtain new prices, until the steady state is reached, where both prices and factor

Figure 3.1: Resource abundance and inter-industry trade in natural resources



Source: Author's calculation from the Wealth Accounting and Comtrade Databases

use are constant.

We take the traditional production based perspective on sustainability, as our central aim is to describe the evolution of consumption and wealth with its subcomponents in an open economy context. Trade is a well-established source of productivity enhancement. It also has an impact on the productive structure of countries. This impact is important for sustainability as it may hasten the depletion of natural capital and reduce incentives for optimal domestic reinvestment. Our results have implications for sustainability indicators, suggesting that income gains from increased specialisation should be reinvested if they are obtained through increased natural resources intensity in production.

An interesting feature of our setting is the possibility to control for the degree of openness, in direct relation with the production functions. The model also allows for the comparison of different trade patterns. Traditionally, sustainability models of international trade were set in a Ricardian framework, as in [Brander and Taylor \(1998\)](#). We chose an HO structure as better suited to assess the evolution of relative endowments. An other important motivation for an HO structure is the observation (explored further in chapter 4 section II) that resources rich countries tend to stick to traditional inter-industry trade in natural capital intensive goods (see figure 3.1).

The multi-cone world derived from the breakdown of FPE seems also to be a valid start to study trade relationships between countries with strongly asymmetric endowments (see figure 3.3). It should also be noted that even if HO theory somewhat fell from grace with the explosion of intra-industry and intra-firm trade, its validity is regularly reasserted in a variety of studies

from [Trefler \(1993\)](#) to [Antweiler et al. \(2001\)](#) and [Crozet and Trionfetti \(2013\)](#). The functional separation between the static and the dynamic model allows us to impose a trade structure and derive conclusion on price formation, while having (relative) freedom on the dynamics. It seems also consistent with the reality of firm production, where factor endowments are fixed in the short run, not in the long run.

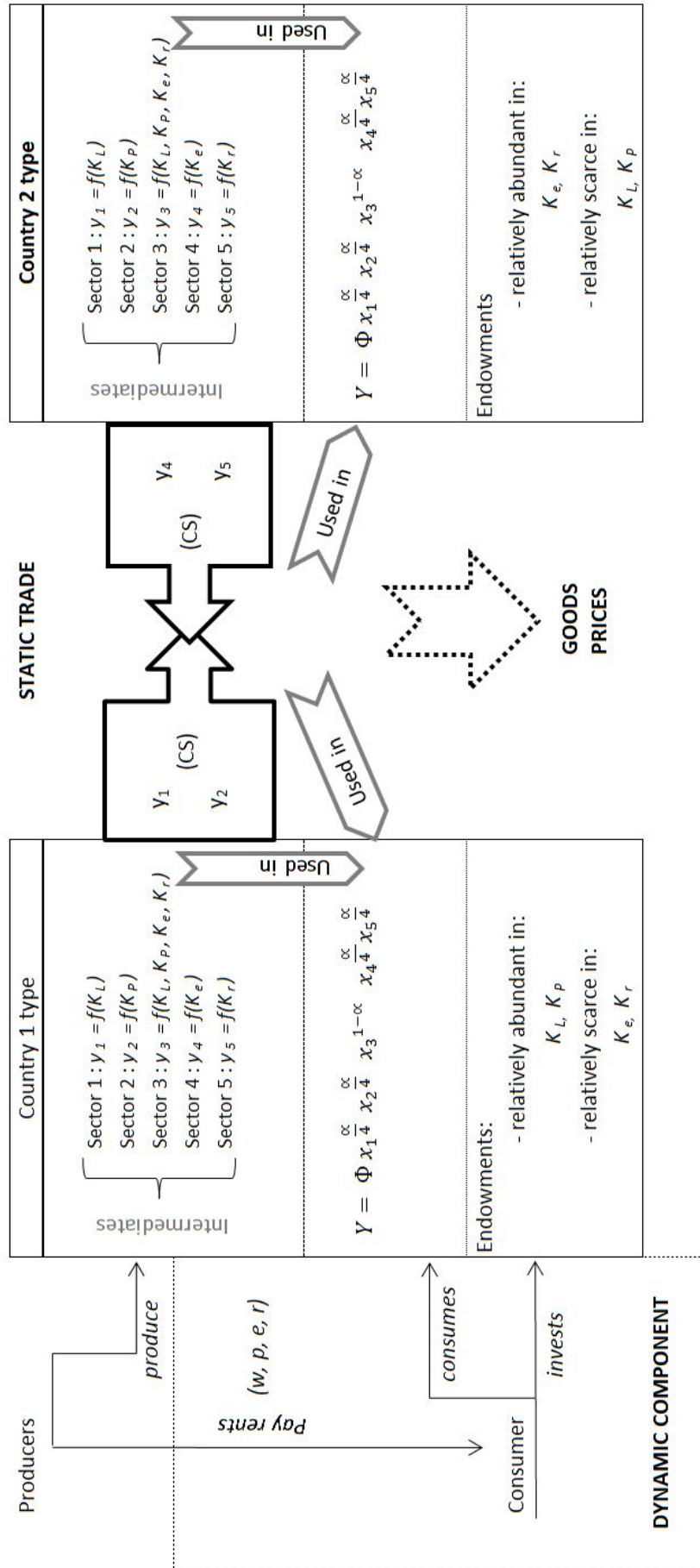
In section [II.1](#) we present the static trade equilibrium, describing production technologies and the conditions associated with the integrated equilibrium (IE) and complete specialisation (CS) equilibrium. In section [II.2](#) we present the dynamic model, notably the dynamics of factor accumulation.

II.1 The static equilibrium

We consider two identical countries. Those two countries have the same production technologies and preferences. Each economy is composed of a set of identical consumers, who owns all the instruments of wealth/production factors. There are four factors in this economy: labour K_l , produced capital K_p , non-renewable exhaustible resources K_e and renewable exhaustible resources K_r . The economy produces one final good Y which is not traded. This good can be consumed or invested. There are then five intermediate goods that can potentially be traded. Those intermediates are produced using factor prices according to the production functions. Those intermediates are then used to produce the final good. We assume perfect competition and perfect information regarding factors. Consequently, the long run profits are null and full employment is guaranteed.

The entirety of a given endowment is used every period so that factor use is equal to factor endowment. This assumption is problematic for the dynamics of non renewable exhaustible resources. We discuss this in section [II.2](#). We also assume that capital is immobile internationally: accumulation and de-cumulation occur through the investment dynamics. This assumption although unrealistic in the case of labour and produced capital, makes sense for natural capital. Exhaustible resources are always transformed, even marginally, in the country of origin. The model is divided between a static component, setting prices and controlling for market general equilibrium and a dynamic component determining the optimal investment/depletion path. The general structure of the model is summarised in figure [3.2](#).

Figure 3.2: Structure of the model



Source: Author

II.1.1 Production Technologies and trade patterns

Consider two countries with the same production structure, one final good and five intermediate goods. The final good is produced using a Cobb-Douglas function², while intermediates are produced using a simple one for one production function. As a consequence, we also assume constant returns to scale in production. The production function for the final good Y is:

$$Y = \Phi y_{1,i}^{\alpha/4} y_{2,i}^{\alpha/4} y_{3,i}^{1-\alpha} y_{4,i}^{\alpha/4} y_{5,i}^{\alpha/4} \quad (3.1)$$

Countries are indexed using the letter j and goods using the letter i . y_i and x_i are respectively quantities produced and consumed. Those are necessarily the same in autarky but they need to be balanced under trade. Φ represents total factor productivity (assuming Hicks-neutral technology) while α is the usual Cobb-Douglas parameter for input allocation. There are five intermediate goods x_1, x_2, x_3, x_4 and x_5 in both countries. Those five intermediate goods can potentially be traded. They are produced using the following production functions:

$$y_{1,i} = K_{l,i} \quad (3.2)$$

$$y_{2,i} = K_{p,i} \quad (3.3)$$

$$y_{3,i} = (K_{l,i} K_{p,i} K_{e,i} K_{r,i})^{\frac{1}{4}} \quad (3.4)$$

$$y_{4,i} = K_{e,i} \quad (3.5)$$

$$y_{5,i} = K_{r,i} \quad (3.6)$$

With K_l labour, K_p produced capital, K_e exhaustible non-renewable resources and K_r exhaustible renewable resources. Factors are allocated between intermediates, which are in turn used for the production of the final good. Our economies are therefore maximising (3.1) subject to intermediate production functions (3.2) to (3.6):

$$y_{1,i} = \lambda K_{l,i} \quad (3.7)$$

$$y_{2,i} = \gamma K_{p,i} \quad (3.8)$$

$$y_{3,i} = ((1-\lambda)K_{l,i})^{\frac{1}{4}} ((1-\gamma)K_{p,i})^{\frac{1}{4}} ((1-\omega)K_{e,i})^{\frac{1}{4}} ((1-\iota)K_{r,i})^{\frac{1}{4}} \quad (3.9)$$

$$y_{4,i} = \omega K_{e,i} \quad (3.10)$$

$$y_{5,i} = \iota K_{r,i} \quad (3.11)$$

$$\sum_{i=1}^3 p_i x_{i,j} = \sum_{i=1}^3 p_i y_{i,j} \quad (3.12)$$

2. In an early version of their model, [Cunat and Maffezzoli \(2003\)](#) use CES functions instead, which allow them to control for the inter-temporal elasticity of substitution between factors of production.

With β, γ, ω and λ the shares used in the production of the intermediates and (3.12) the market clearing conditions³. Let us assume for the moment that factor endowments are the same across countries. This allows us to ignore the market clearing conditions, as presented below. As shown in appendix A, this yields $\gamma = \iota = \omega = \lambda = \alpha$. The coefficient α determines the allocation of factors across intermediates and at the same time the relative use of intermediates y_1, y_2, y_4 and y_5 against the use of y_3 in the production of the final good.

A first observation regarding α is warranted. If $\alpha = 0$, good y_3 is the only one entering in the final good production. In this scenario, allocation shares are meaningless and endowments are allocated entirely to the production of good y_3 . Symmetrically, if $\alpha = 1$, good y_3 does not enter in the production of the final good. With the good three sector non existent, each factor is used by a single sector, and the full endowment of a given factor is therefore allotted to the relevant sector.

Consider now that endowments differ across countries. Assume country 1 is relatively well-endowed in labour and produced capital and country 2 is relatively well-endowed in renewable and non-renewable exhaustible resources. Assume also that trade is always balanced between the two countries. We adopt here a rather traditional pattern of specialisation between developed and developing countries, North and South. But it also matches the pattern of structural change (López et al. 2007) as countries switch from exhaustible sources of wealth to instruments based on human capacities. Countries will engage in trade of intermediates as asymmetric factor endowments give each country a comparative advantage in the production of two intermediates. To predict the pattern of trade in a world with more than two factors, we use the chain ranking of factor endowments, as defined by Vanek (1968). World capital stocks are the sum of countries' capital stocks:

$$K_l = K_{l,1} + K_{l,2} \tag{3.13}$$

$$K_p = K_{p,1} + K_{p,2} \tag{3.14}$$

$$K_e = K_{e,1} + K_{e,2} \tag{3.15}$$

$$K_r = K_{r,1} + K_{r,2} \tag{3.16}$$

The chain ranking prediction states that a country will produce the goods intensive in factors it is relatively well endowed with. With more than two factors, those are all the factors for which the country has a world share superior to its share of world income. A country's income is expressed as the sum of factor payments times factor use, therefore countries income can be

3. Which are non-binding under autarky.

expressed as:

$$W_1 = w_1 K_{l,1} + p_1 K_{p,1} + e_1 K_{e,1} + r_1 K_{r,1} \quad (3.17)$$

$$W_2 = w_2 K_{l,2} + p_2 K_{p,2} + e_2 K_{e,2} + r_2 K_{r,2} \quad (3.18)$$

$$W = W_1 + W_2 \quad (3.19)$$

With w the payment for labour, p for produced capital, e for non-renewable exhaustible resources and r for renewable exhaustible resources. Considering our assumption regarding endowment distribution, we obtain the following chain ranking:

$$\frac{K_{e,1}}{K_e} \leq \frac{K_{r,1}}{K_r} < \frac{W_1}{W} < \frac{K_{l,1}}{K_l} \leq \frac{K_{p,1}}{K_p} \quad (3.20)$$

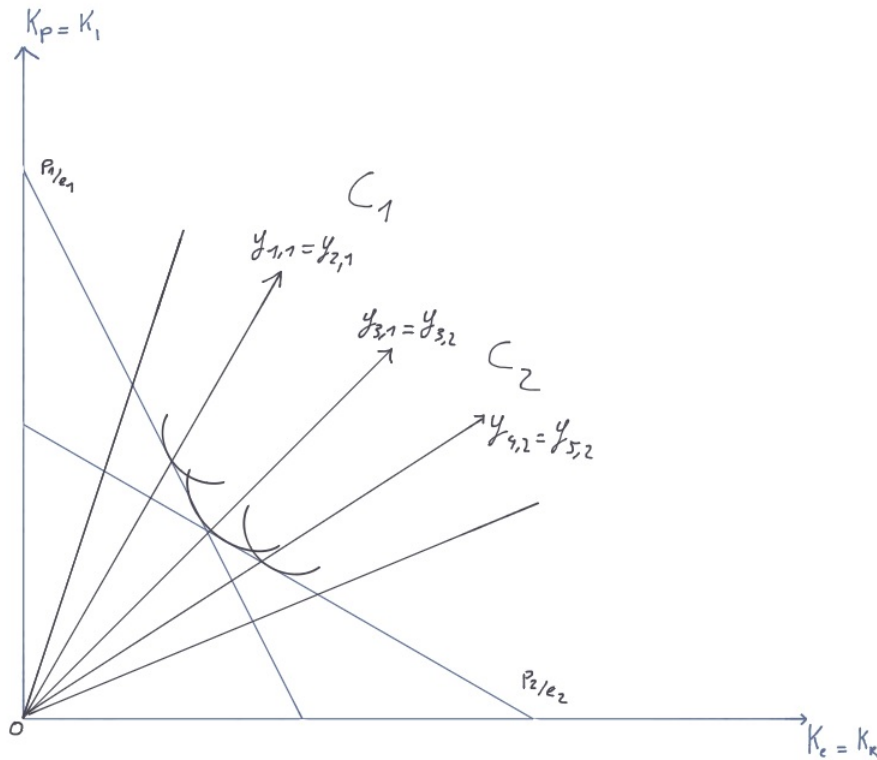
$$\frac{K_{l,2}}{K_l} \leq \frac{K_{p,2}}{K_p} < \frac{W_2}{W} < \frac{K_{e,2}}{K_e} \leq \frac{K_{r,2}}{K_r} \quad (3.21)$$

This is the multi-factor version of the Heckscher-Ohlin Theorem, as presented by [Vanek \(1968\)](#). A first observation is needed here. As in [Cuñat and Maffezzoli \(2004\)](#), we have more goods than factors, hence under FPE we only know that the North will export labour and produced capital intensive goods, while the South exports exhaustible resources intensive ones. This does not prevent the equilibrium to be unique as any distribution of factor endowments yields a single set of prices for goods and factors. Full employment requires both countries, for as long as they have positive endowments in all the factors, to produce intermediates using all endowments for $\alpha \in]0 : 1[$.

As presented in [Ohlin \(1933\)](#), FPE depends on the distribution of factor endowments. If the distribution is “too diverse”, FPE will not occur. When FPE breaks down, countries give up on the two goods in which they have no comparative advantage to produce good y_3 and the two in which they have a comparative advantage. The trade pattern is then conform to the “complete specialisation” (CS) case in [Cuñat and Maffezzoli \(2004\)](#): instead of using world prices, firms use domestic prices. The breakdown of FPE ends the “separability” property of Heckscher-Ohlin model, under which an evolution of domestic factor output had no impact on factor prices. In a HO model factor prices only depend on world factor ratios.

The CS case is therefore really interesting in a dynamic setting, allowing to investigate the behaviour of agents confronted to free trade with unequal factor prices, a more realistic situation. Our model manages to replicate this nice “nested” setting from [Cuñat and Maffezzoli \(2004\)](#). The price to pay for this is to maintain the symmetry in the model, so that each country’s endowments entitle it to a comparative advantage in two sectors. As in [Deardorff \(1994a\)](#), FPE breakdown confines countries into overlapping cones of diversification based on

Figure 3.3: A multi-cone two country setting



Source: Author

comparative advantage. Both have a specific part of the cone where goods y_1, y_2, y_4 and y_5 are produced, and an overlapping part with the other for good y_3 . A diagrammatic representation of the FPE case can be obtained under the assumption that $K_l = K_p, K_e = K_r, w_1 = p_1$ and $e_2 = r_2$ (see figure 3.3).

A crucial feature of the model is therefore the determination of the FPE condition, the factor endowment ratio for which global FPE is impossible. Once it is carried out, the model allows the investigation of several scenarios (autarky, free trade under CS and free trade under FPE). Those possible settings are the core of the analysis. We will compare the evolution of factor use in autarky and free trade, questioning in line with Bazhanov (2010) the importance of initial conditions on convergence when opening-up to trade. We will now present those two equilibrium setting under FPE and CS articulated around the FPE condition.

II.1.2 The Integrated Equilibrium

Free-trade under FPE yields an integrated equilibrium in the sense that confronted with the same factor prices, goods prices, production functions and preferences, the two trading countries effectively behave as one, in line with the angel parable (Samuelson 1949) and the integrated world economy in Dixit and Norman (1980). Factor prices are equalised across countries:

$$w = w_1 = w_2 \quad (3.22)$$

$$p = p_1 = p_2 \quad (3.23)$$

$$e = e_1 = e_2 \quad (3.24)$$

$$r = r_1 = r_2 \quad (3.25)$$

The integrated equilibrium is characterised by the separability assumption as in any model of the HO class. Factor prices depend on the world ratios of factor endowments. This fits the exogenous prices perspective of capital gains from trade (Hartwick 1995). A comparison between the integrated and the autarky equilibrium will be presented in section III. In this section we drop the country subscript and solve for total world endowments. To solve the integrated equilibrium for factor prices, we use equations (3.1) and (3.2) to (3.6). We first minimize the budget constraint:

$$P_y = P_1x_1 + P_2x_2 + P_3x_3 + P_4x_4 + P_5x_5 \quad (3.26)$$

Subject to (3.1). We take the final good Y as the *numéraire*, so that $P_y = 1$. This gives us the marginal cost of the final good:

$$1 = Xp_3^{1-\alpha}(P_1P_2P_4P_5)^{\frac{\alpha}{4}} \quad (3.27)$$

With:

$$X = [(\Phi(\frac{\alpha}{4})^\alpha(1-\alpha)^{1-\alpha})]^{-1} \quad (3.28)$$

$$(3.29)$$

See appendix B for more details. To obtain the unit cost in the intermediate goods sectors, we maximise profits sector by sector:

$$\Pi_1 = P_1 y_1 - w K_l \quad (3.30)$$

$$\Pi_2 = P_2 y_2 - p K_p \quad (3.31)$$

$$\Pi_3 = P_3 y_3 - w K_l - p K_p - e K_e - r K_r \quad (3.32)$$

$$\Pi_4 = P_4 y_4 - e K_e \quad (3.33)$$

$$\Pi_5 = P_5 y_5 - r K_r \quad (3.34)$$

The first order conditions with respect to the relevant factor endowment give us the marginal cost equations. The program for good y_3 is slightly more complex, requiring to derive the four FOC with respect to the four factors, then to simplify through substitutions. This gives us five marginal cost equations for the intermediates:

$$P_1 = w \quad (3.35)$$

$$P_2 = p \quad (3.36)$$

$$P_3 = 4(e p r w)^{\frac{1}{4}} \quad (3.37)$$

$$P_4 = e \quad (3.38)$$

$$P_5 = r \quad (3.39)$$

$$(3.40)$$

The technical-economic equilibrium is reached when it is equivalent to use one intermediate or the other. Using the first order conditions for cost minimisation of the final good, we obtain the following market share conditions:

$$P_1 x_1 = P_2 x_2 \quad (3.41)$$

$$P_4 x_4 = P_5 x_5 \quad (3.42)$$

$$P_1 x_1 = -\frac{\alpha P_3 x_3}{4(\alpha - 1)} \quad (3.43)$$

$$P_1 x_1 = p x_4 \quad (3.44)$$

$$(3.45)$$

See appendix B for details. Finally we set the market equilibrium conditions on all markets. This is straightforward for the intermediates. Market clearing for factor endowments require

the marginal contribution of the considered factor to equate its costs:

$$\sum_{i=1}^5 x_i = y_i \quad (3.46)$$

$$\sum_{i=1}^5 \frac{c_i(w, p, e, r)}{w} = K_l \quad (3.47)$$

$$\sum_{i=1}^5 \frac{c_i(w, p, e, r)}{p} = K_p \quad (3.48)$$

$$\sum_{i=1}^5 \frac{c_i(w, p, e, r)}{e} = K_e \quad (3.49)$$

$$\sum_{i=1}^5 \frac{c_i(w, p, e, r)}{r} = K_r \quad (3.50)$$

With $X > 0$. The system has 19 equations and 19 unknowns. The unknowns are $P_1, P_2, P_3, P_4, P_5, x_1, x_2, x_3, x_4, x_5, y_1, y_2, y_3, y_4, y_5, w, p, e$ and r . We solve the system by substituting marginal costs and market shares equations into the market clearing conditions. This gives us the following solution for factor prices and goods prices:

$$P_1 = w = E(K_l^{-\frac{3}{4}} K_p^{\frac{1}{4}} K_e^{\frac{1}{4}} K_r^{\frac{1}{4}}) \quad (3.51)$$

$$P_2 = p = E(K_p^{-\frac{3}{4}} K_l^{\frac{1}{4}} K_e^{\frac{1}{4}} K_r^{\frac{1}{4}}) \quad (3.52)$$

$$P_4 = e = E(K_e^{-\frac{3}{4}} K_l^{\frac{1}{4}} K_p^{\frac{1}{4}} K_r^{\frac{1}{4}}) \quad (3.53)$$

$$P_5 = r = E(K_r^{-\frac{3}{4}} K_l^{\frac{1}{4}} K_p^{\frac{1}{4}} K_e^{\frac{1}{4}}) \quad (3.54)$$

$$P_3 = 4E \quad (3.55)$$

$$(3.56)$$

With $E = X^{-1}4^{\alpha-1}$. As in [Cuñat and Maffezzoli \(2004\)](#), P_3 is invariant because of the symmetry in the model. Due to the form of the production functions in intermediates, factor prices are equalised to the relevant intermediate price. The production of intermediates will come as no surprise:

$$x_1 = \alpha K_l \quad (3.57)$$

$$x_2 = \alpha K_l \quad (3.58)$$

$$x_3 = (1 - \alpha)(K_l K_p K_e K_r)^{\frac{1}{4}} \quad (3.59)$$

$$x_4 = \alpha K_e \quad (3.60)$$

$$x_5 = \alpha K_r \quad (3.61)$$

With the sectoral allocation of factors presented above, the description of the integrated equilibrium is now complete.

II.1.3 The Factor Price Equalisation condition

FPE is determined by the world distribution of endowments, technological discrepancies and transaction costs. As we assumed away transactions costs and cross-country technological differences, FPE depends solely on the distribution of factor endowments. As we saw above, the parameter α determines factor allocation across sectors. Therefore, it also provides information regarding trade flows and the likelihood of FPE. The higher α the more of a given endowment is allocated to the production of intermediates constituting the comparative advantage.

With this in mind, it is easy to picture the distribution for which FPE will occur. The [Vanek \(1968\)](#) chain ranking states clearly that FPE will *de facto* occur if factor endowments are equal. Starting from this theoretical case when endowments are equally distributed between countries (and the incentive to trade is null in an HO model), FPE will break down at some point when the distribution becomes too asymmetric. If $\alpha = 0$ both countries produce good y_3 with equal factor intensities. There is no incentive to trade and both countries are effectively in autarky.

Conversely, if $\alpha = 1$, both countries have an incentive to specialise according to their comparative advantage, and import the bulk of the other intermediates from the other country. In this setting, country 1 specialises into goods y_1 and y_2 and country 2 in goods y_4 and y_5 respectively. Factors K_e and K_r in country 1 and K_l and K_p in country 2 are residually used to produce the disadvantaged intermediates, so that specialisation is not complete. Between those two polar cases lie the area in which all intermediates are produced between the two countries. Depending on the value of α , the production takes place either in CS under IE.

To determine the FPE condition, it is better to think of the world as a single country and look for conditions that may lead to the breakdown of FPE rather than imagining how to bring FPE in a two states setting. Our demonstration for the FPE condition is quite similar to the one in [Cuñat and Maffezzoli \(2004\)](#) as we also have only two countries. Consider that factor endowments in one of the two countries, starting from an equal distribution between the two

countries differ from a symmetric share ε :

$$K_{l,1} = \left(\frac{1}{2} + \varepsilon\right)K_l \quad (3.62)$$

$$K_{l,2} = \left(\frac{1}{2} - \varepsilon\right)K_l \quad (3.63)$$

$$K_{p,1} = \left(\frac{1}{2} + \varepsilon\right)K_p \quad (3.64)$$

$$K_{p,2} = \left(\frac{1}{2} - \varepsilon\right)K_p \quad (3.65)$$

$$K_{e,1} = \left(\frac{1}{2} - \varepsilon\right)K_e \quad (3.66)$$

$$K_{e,2} = \left(\frac{1}{2} + \varepsilon\right)K_e \quad (3.67)$$

$$K_{r,1} = \left(\frac{1}{2} - \varepsilon\right)K_r \quad (3.68)$$

$$K_{r,2} = \left(\frac{1}{2} + \varepsilon\right)K_r \quad (3.69)$$

With $0 < \varepsilon < \frac{1}{2}$. As there are more than two factors, no 2D diagrammatic representation is possible for the FPE set. What we are looking for is a share of capital in country 1 (and the symmetric share in country 2) for which FPE cannot occur. Assume α is the same in both countries. The total demand for factors from the optimal factor allocation is equal to $\alpha K_{l,1}$ and $\alpha K_{p,1}$ for goods y_1 and y_2 in country 1 and $\alpha K_{e,2}$ and $\alpha K_{r,2}$ for goods y_4 and y_5 in country 2. Under the production pattern identified supra, in IE goods y_1 and y_2 are only produced in country 1. Therefore, the share α of $K_{l,1}$ and $K_{p,1}$ used in country 1 are shares of the *world* stock of those factors: $\alpha K_{l,1} = \alpha K_l$ and $\alpha K_{p,1} = \alpha K_p$.

Following the same logic, $\alpha K_{e,2} = \alpha K_e$ and $\alpha K_{r,2} = \alpha K_r$. If we now focus on labour in country 1, the rest of the endowment will be used to produce good y_3 . Assume $0 < \alpha < 0.5$. Assume then that while our hypothetical country 1 is relatively well-endowed in K_l and K_p , both country 1 and country 2 are endowed with one unit of K_e and one unit of K_r ⁴. We can then write for country 1:

$$\frac{K_{l,3}}{K_{e,3}} \left(\frac{1}{2} K_e\right) = \frac{K_l}{K_e} \left(\frac{1}{2} K_e\right) = \frac{1}{2} K_l \quad (3.70)$$

With $0 < \alpha < 0.5$, $K_{l,3}$ cannot be less than half of the total world stock. In the integrated equilibrium perspective, the local $K_{l,3}$ to $K_{e,3}$ ratio⁵ is equal to the world ratio as the two dummy regions behave as a single world. Adding the two allocations of K_l gives us a limit

4. This would arguably destroy the incentive for trade in a HO setting as country 2 has now no comparative advantage. For the sake of the counterfactual we are presenting here, it is better to think in terms of the breakdown of a country into two regions rather than in terms of convergence by trade.

5. The demonstration can be conducted with K_r instead of K_e as the shares are the same by symmetry.

$K_1^{FPE} = \frac{1}{2}K_l + \alpha K_l = (\frac{1}{2} + \alpha)K_l$. Hence, ε can take values in the range $(0, \alpha)$, as an asymmetry in factor endowments above α would break FPE. It is straightforward to show that the same limit holds for $K_{p,1}$ and with respect to the same factors K_e and K_r . Similarly, a condition in terms of country 2 comparative advantage could be found based on $K_{e,2}$ or $K_{r,2}$ with respect to K_l and K_p . Therefore, FPE breaks down in our case when *any* of these conditions is broken.

Adding more factors to the original model creates an asymmetry here. The violation of the FPE condition for *one* factor is enough to prevent FPE. This assumption implies that when testing for the violation of FPE one occurrence is enough, but an endowment distribution compatible with FPE should abide by the FPE condition for *all* factors. When the FPE condition is violated, the two countries are behaving again like separate entities, using different factor price ratios. This structure corresponds to the complete specialisation (CS) case we will now present.

II.1.4 The Complete Specialisation Equilibrium

As FPE breaks down, countries will face different domestic factor prices. Country one becomes the sole producer of goods y_1 and y_2 , while country 2 becomes the sole producer of goods y_4 and y_5 . Good y_3 is still produced in both countries, as it requires the four factors as inputs. For $\varepsilon \in (\alpha, \frac{1}{2})$ we have $y_{1,4} = 0$, $y_{1,5} = 0$, $y_{2,1} = 0$ and $y_{2,2} = 0$. The set of equilibrium equations is extended to take into account different factor prices in the two countries, while P_1 and P_2 are determined solely by country 1 factor prices and P_4 and P_5 solely by country 2 factor prices. The price equal unit cost equations are:

$$1 = \Xi p_3^{1-\alpha} (p_1 p_2 p_4 p_5)^{\frac{\alpha}{4}} \tag{3.71}$$

$$P_1 = w_1 \tag{3.72}$$

$$P_2 = p_1 \tag{3.73}$$

$$P_3 = 4(e_1 p_1 r_1 w_1)^{\frac{1}{4}} \tag{3.74}$$

$$P_3 = 4(e_2 p_2 r_2 w_2)^{\frac{1}{4}} \tag{3.75}$$

$$P_4 = e_2 \tag{3.76}$$

$$P_5 = r_2 \tag{3.77}$$

The consumption shares:

$$P_1x_1 = P_2x_2 \quad (3.78)$$

$$P_1x_1 = P_5x_5 \quad (3.79)$$

$$P_1x_1 = -\frac{\alpha P_3(x_{3,1} + x_{3,2})}{4(\alpha - 1)} \quad (3.80)$$

$$P_1x_1 = P_4x_4 \quad (3.81)$$

See appendix B for details. Finally, the market clearing conditions for both goods and factors:

$$x_{1,1} + x_{1,2} = y_{1,1} \quad (3.82)$$

$$x_{2,1} + x_{2,2} = y_{2,1} \quad (3.83)$$

$$x_{3,1} + x_{3,2} = y_{3,1} + y_{3,2} \quad (3.84)$$

$$x_{4,1} + x_{4,2} = y_{4,2} \quad (3.85)$$

$$x_{5,1} + x_{5,2} = y_{5,2} \quad (3.86)$$

$$y_1 + (e_1 p_1 r_1)^{\frac{1}{4}} (w_1)^{-\frac{3}{4}} y_{3,1} = K_{l,1} \quad (3.87)$$

$$y_2 + (e_1 w_1 r_1)^{\frac{1}{4}} (p_1)^{-\frac{3}{4}} y_{3,1} = K_{p,1} \quad (3.88)$$

$$(w_1 p_1 r_1)^{\frac{1}{4}} (e_1)^{-\frac{3}{4}} y_{3,1} = K_{e,1} \quad (3.89)$$

$$(e_1 p_1 w_1)^{\frac{1}{4}} (r_1)^{-\frac{3}{4}} y_{3,1} = K_{r,1} \quad (3.90)$$

$$(e_2 p_2 r_2)^{\frac{1}{4}} (w_2)^{-\frac{3}{4}} y_{3,2} = K_{l,2} \quad (3.91)$$

$$(e_2 w_2 r_2)^{\frac{1}{4}} (p_2)^{-\frac{3}{4}} y_{3,2} = K_{p,2} \quad (3.92)$$

$$y_4 + (w_2 p_2 r_2)^{\frac{1}{4}} (e_2)^{-\frac{3}{4}} y_{3,2} = K_{e,2} \quad (3.93)$$

$$y_5 + (e_2 p_2 w_2)^{\frac{1}{4}} (r_2)^{-\frac{3}{4}} y_{3,2} = K_{r,2} \quad (3.94)$$

With $\Xi = [(\Phi(\alpha/4)^\alpha(1-\alpha)^{1-\alpha})^{-1}] > 0$. Note that in CS market clearing is performed at the global level, as the country level production is traded in the global market. This is a system of 24 equations with 25 unknowns. As P_3 depends on both country 1 and country 2 factor prices, a direct expression for factor prices as a function of capital stocks can not be deduced from the system of equations. The resolution of the system to provide factor prices expressed in terms of factor endowments needs to be done in two steps. This is because of the indeterminacy introduced by unequal factor prices. The first step relates factor endowments to factor price ratios, while the second step relates factor prices to factor price ratios. Substitution and

simplification of market clearing conditions gives the equilibrium factor use conditions:

$$\frac{e_1}{r_1} = \frac{K_{r,1}}{K_{e,1}} \quad (3.95)$$

$$\frac{p_1}{w_1} = \frac{K_{l,1}}{K_{p,1}} \quad (3.96)$$

$$\frac{p_2}{w_2} = \frac{K_{l,2}}{K_{p,2}} \quad (3.97)$$

$$\frac{e_2}{r_2} = \frac{K_{r,2}}{K_{e,2}} \quad (3.98)$$

Those equilibrium conditions are then used to define the relation between factor endowments and factor price ratios. We define the ratios as:

$$\sigma = \frac{w_2}{e_2} \quad (3.99)$$

$$\tau = \left(\frac{e_1}{w_1}\right)^{-1} \quad (3.100)$$

$$\kappa = \frac{p_2}{r_2} \quad (3.101)$$

$$\nu = \left(\frac{r_1}{p_1}\right)^{-1} \quad (3.102)$$

Rearranging the market clearing conditions of the CS equilibrium using equilibrium conditions to obtain factor price ratios finally yields to following system of four equations:

$$K_{l,1} + \frac{K_{e,1}}{\tau(\alpha - 1)} = \frac{(\alpha\sigma^{\frac{1}{2}}K_{e,1}^{\frac{1}{4}}K_{l,1}^{\frac{1}{4}}K_{l,2}^{\frac{3}{4}}K_{p,2}^{\frac{1}{4}}K_{r,2}^{\frac{1}{4}})}{((1 - \alpha)\tau^{\frac{1}{2}}K_{e,2}^{\frac{1}{4}}K_{p,1}^{\frac{1}{4}}K_{r,1}^{\frac{1}{4}})} \quad (3.103)$$

$$K_{p,1} + \frac{K_{r,1}}{\nu(\alpha - 1)} = \frac{(\alpha\kappa^{\frac{1}{2}}K_{e,2}^{\frac{1}{4}}K_{l,2}^{\frac{1}{4}}K_{p,1}^{\frac{1}{4}}K_{p,2}^{\frac{3}{4}})}{((1 - \alpha)\nu^{\frac{1}{2}}K_{l,1}^{\frac{1}{4}}K_{r,2}^{\frac{1}{4}})} \quad (3.104)$$

$$K_{e,2} + \frac{K_{l,2}\sigma}{(\alpha - 1)} = \frac{(\alpha(\frac{\sigma}{\nu})^{\frac{1}{2}}K_{e,2}^{\frac{1}{4}}K_{l,1}^{\frac{1}{4}}K_{l,2}^{\frac{1}{4}})}{((1 - \alpha)K_{p,1}^{\frac{1}{4}}K_{p,2}^{\frac{1}{4}}K_{r,2}^{\frac{1}{4}})} \quad (3.105)$$

$$K_{r,2} + \frac{K_{p,2}\sigma}{(\alpha - 1)} = \frac{(\alpha\kappa^{\frac{1}{2}}K_{e,1}^{\frac{3}{4}}K_{p,1}^{\frac{1}{4}}K_{p,2}^{\frac{1}{4}}K_{r,1}^{\frac{1}{4}}K_{r,2}^{\frac{1}{4}})}{((1 - \alpha)\tau^{\frac{1}{2}}K_{e,2}^{\frac{1}{4}}K_{l,1}^{\frac{1}{4}}K_{l,2}^{\frac{1}{4}})} \quad (3.106)$$

This is the first step of the definition of factor prices. For the second step we use the unit cost equation for the final good 3.71, to obtain factor prices as a function of endowments and factor

price ratios:

$$w_1 = E\left(\frac{K_{p,1}}{K_{l,1}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}}(\nu\tau)^{\frac{1}{4}-\frac{\alpha}{8}} \quad (3.107)$$

$$p_1 = E\left(\frac{K_{l,1}}{K_{p,1}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}}(\nu\tau)^{\frac{1}{4}-\frac{\alpha}{8}} \quad (3.108)$$

$$e_1 = E\left(\frac{K_{r,1}}{K_{e,1}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}}(\nu\tau)^{-\frac{1}{4}-\frac{\alpha}{8}} \quad (3.109)$$

$$r_1 = E\left(\frac{K_{e,1}}{K_{r,1}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}}(\nu\tau)^{-\frac{1}{4}-\frac{\alpha}{8}} \quad (3.110)$$

$$w_2 = E\left(\frac{K_{p,2}}{K_{l,2}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}+\frac{1}{4}}(\nu\tau)^{-\frac{\alpha}{8}} \quad (3.111)$$

$$p_2 = E\left(\frac{K_{l,2}}{K_{p,2}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}+\frac{1}{4}}(\nu\tau)^{-\frac{\alpha}{8}} \quad (3.112)$$

$$e_2 = E\left(\frac{K_{r,2}}{K_{e,2}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}-\frac{1}{4}}(\nu\tau)^{-\frac{\alpha}{8}} \quad (3.113)$$

$$r_2 = E\left(\frac{K_{e,2}}{K_{r,2}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}-\frac{1}{4}}(\nu\tau)^{-\frac{\alpha}{8}} \quad (3.114)$$

Factor prices are a function of both factor price ratios and factor use. Goods prices can be deduced from the unit cost conditions:

$$P_1 = w_1 = E\left(\frac{K_{p,1}}{K_{l,1}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}}(\nu\tau)^{\frac{1}{4}-\frac{\alpha}{8}} \quad (3.115)$$

$$P_2 = p_1 = E\left(\frac{K_{l,1}}{K_{p,1}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}}(\nu\tau)^{\frac{1}{4}-\frac{\alpha}{8}} \quad (3.116)$$

$$P_3 = E\left(\frac{(\kappa\sigma)^{\frac{\alpha}{2}}}{(\nu\tau)^{\frac{\alpha}{2}}}\right)^{\frac{1}{4}} \quad (3.117)$$

$$P_4 = e_2 = E\left(\frac{K_{r,2}}{K_{e,2}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}-\frac{1}{4}}(\nu\tau)^{-\frac{\alpha}{8}} \quad (3.118)$$

$$P_5 = r_2 = E\left(\frac{K_{e,2}}{K_{r,2}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}-\frac{1}{4}}(\nu\tau)^{-\frac{\alpha}{8}} \quad (3.119)$$

As one would expect from the trade patterns, prices for goods y_1, y_2, y_4 and y_5 are equal to the relevant domestic prices, depending on domestic factor endowments. The price for good 3 depends on neither country's factor endowments but on both country's factor price ratios. This is what we would expect from figure 3.3. Our presentation of the CS equilibrium is now complete. We can now compute the static equilibrium for unequal factor prices. We will now turn to the dynamic equilibrium.

II.2 The dynamic equilibrium

To model the dynamics of capital accumulation, we use the discrete time Ramsey model as in [Cuñat and Maffezzoli \(2004\)](#). Recursive growth model as in [Stokey et al. \(1989\)](#) and [Mehra \(2006\)](#) allows for the use of dynamic programming to obtain the steady-state values of a system. The development of numerical methods helps in solving problems such as ours when an analytical solution cannot be found. The two static trade configurations in our setting will determine factor prices, goods prices and the quantities produced.

The dynamic recursive model is concerned with investment in and depletion of factor endowments. Consider that country one and country two are populated with a continuum of identical and infinitely lived agents. In line with the assumption of perfect competition in the static model, we assume perfect information and foresight. Agents being infinitely lived, we also assume *de facto* intergenerational equity. Our continuum assumption allows us to use a single representative agent for all the agents in the economy. This rational agent maximises utility over an infinite horizon. Utility is the sum of discounted consumption flows over an infinite number of periods:

$$U_{j,t} = \sum_{s=t}^{\infty} \beta^{s-t} \ln c_{j,t} \quad (3.120)$$

β is the pure rate of time preference, c is consumption, s indicates the starting period and t the current period. We assume that the representative agent owns all the instruments of wealth available in his country. The use of labour K_l and produced capital K_p generates the usual income flows. Non-renewable exhaustible resources are assumed to be extracted against the payment of a royalty e set at the marginal cost so that extraction is optimal. The same logic applies to renewable exhaustible resources, with the exception that the resource pool regenerates itself via natural growth and pays a royalty r . We assume there are neither commons nor free-access resources in both countries, so that property rights definition is not an issue. There is also no transboundary ownership of resources, so countries can only rely on their own capital stocks to maintain consumption. We assume that decisions are taken under perfect foresight so that the representative agent optimises future consumption based on wealth, in a permanent-income perspective ([Ventura 1997](#)).

The four factors have their own dynamics of accumulation, based on physical differences:

Labour K_l is accumulated by investment in education. The labour endowment of a given country is equal to the part of the population with adequate training to enter the production process. Therefore, the value of labour is the monetary equivalent of all the training, or education, embedded in the labour force. The reward for labour is the wage w .

Produced Capital K_p is accumulated through investment. It depreciates every period by a constant parameter δ . Produced capital is owned by consumers and rented by firms at a rate p to produce intermediate goods at every period.

Non-Renewable Exhaustible Resources K_e can only be used in the production process, there is no investment. The representative agent does not include exhaustible resources in its budget constraint, as he can not invest to renew them. The reward for exhaustible resources use is the royalties e paid to the representative household by the firms using exhaustible resources in the production process.

Renewable Exhaustible Resources K_r have a rate of natural growth ρ at every period, applied to the current stock. Natural growth is a bonus over investment in renewable resources which takes the form of fish farming for example. The use of the pool is sanctioned by a royalty r .

As we impose on our dynamic model a production structure from the static trade equilibrium, the technical allocation is summarised by two sets of equation. We saw above that factors enter in a symmetrical pattern into intermediate goods production. Intermediates also enter symmetrically into the final good production. Hence, there is no substitutability in factor inputs for the production of intermediates. This production structure strikes us as surprisingly realistic in a world of intertwined supply chains. This limited substitutability also implies that it is more realistic to impose exogenous constraints on the optimisation process regarding some factors to get insight on the actual *ceteris paribus* investment decision.

Based on this stance, we can define our two scenarios of structural change (SC) and increasing comparative advantage (CA). In SC, representative consumers in country one and country two both set the investment path for produced capital to maximise consumption, constrained by exogenous path for labour, exhaustible resource and renewable resources. In CA, country one stick to the SC optimisation plan, but country two optimises investment in renewable resources, constrained by exogenous paths for labour, produced capital and exhaustible resources. The different exogenous paths simulated will be presented in section III.

Formally, the dynamics for the endogenous investment paths⁶ are:

$$K_{p,t+1} = K_{p,t} - \delta K_{p,t} + IK_{p,t} \quad (3.121)$$

$$K_{r,t+1} = K_{r,t} + \rho K_{r,t} + IK_{r,t} \quad (3.122)$$

With $IK_{p,t}$ and $IK_{r,t}$ investment in t . The natural (net) growth of the renewable resource acts as a bonus on top of the needed investment to expand the stock. Each dynamic is applied to

6. It should be noted that de-cumulation of the stock is possible for any instrument of wealth, so that $IK_{p,t}$ and $IK_{r,t}$ can be negative.

the relevant country in the relevant scenario. Even if the other capital stocks are exogenous, they earn income to the consumer while potentially costing him maintenance costs. Special attention was devoted to the dynamics of exhaustible resources. We do not have a standard co-state equation of the usual $S \geq \sum_t^T -R_t$ form with S the total stock and R_t depletion in t . Our assumption of an exogenous path prevents the formation of an optimal path, based on a specification of the Hotelling rule. Still, to model increased scarcity we add a variable cost of extraction for exhaustible resources of the form:

$$TC = xK_{e,j} \quad (3.123)$$

With TC total cost and x an exogenously determined parameter. Under a scenario where quantities extracted are constant, a fixed maintenance cost is paid. This cost turns into a variable cost based on the volume extracted in a scenario of increasing or decreasing extraction. This seems to us an intuitive and realistic way to integrate the pressure induced by increasing scarcity on the consumption possibilities of the representative consumers. We do not impose a similar cost on labour, assuming unless otherwise scripted in the scenario that the representative consumer level of steady state consumption defined by the optimisation process corresponds to a constant population.

Those assumptions illustrate the difference between factor usage in trade models and stock management in environmental and resources economics. In an optimal control problem, the representative agent would decide to use a share of the exhaustible resources stock depending on its return relative to others instruments of wealth. The mathematical modelling behind recursive models is based on the assumption that the whole stock of a given instrument of wealth is used every period. In this setting, the variation of the stock depends on depreciation and investment which subtract or add to the stock.

Combination of this full factor use (full employment of instruments) with an explicit modelling of a stock management behaviour would add greatly to the complexity of the model. Our aim is to study the impact of asymmetry in endowments on steady-state formation and factor use, so that optimal management of each instrument is somewhat secondary. Our modelling strategy based on variable cost of extraction sends the correct incentive in terms of price (the more exhaustible resources are used, the more expensive they get) while keeping the calculation of optima investment reasonably simple. Therefore, we abstract from the explicit modelling of a fixed stock of exhaustible non-renewable resources.

Under SC, both countries face the same budget constraint:

$$\begin{aligned} & w_{j,t}K_{l,j,t} + p_{j,t}K_{p,j,t} + e_{j,t}K_{e,j,t} + r_{j,t}K_{r,j,t} \\ & = c_{j,t} + K_{p,j,t+1} - K_{p,j,t} + \delta K_{p,j,t} + xK_{e,j,t} - \rho K_{r,j,t} \end{aligned} \quad (3.124)$$

Under CA, country one stays under the same constraint while country 2 invests in renewable resources:

$$\begin{aligned} & w_{1,t}K_{l,1,t} + p_{1,t}K_{p,1,t} + e_{1,t}K_{e,1,t} + r_{1,t}K_{r,1,t} \\ & = c_{1,t} + K_{p,1,t+1} - K_{p,1,t} + \delta K_{p,1,t} + xK_{e,1,t} - \rho K_{r,1,t} \end{aligned} \quad (3.125)$$

$$\begin{aligned} & w_{2,t}K_{l,2,t} + p_{2,t}K_{p,2,t} + e_{2,t}K_{e,2,t} + r_{2,t}K_{r,2,t} \\ & = c_{2,t} + K_{r,2,t+1} - K_{r,2,t} - \rho K_{r,2,t} + \delta K_{p,2,t} + xK_{e,2,t} \end{aligned} \quad (3.126)$$

Every period the representative agent gets income from the factors rented/extracted by the representative firms in the intermediate goods sectors and has to choose between consumption and investment.

Maximising (3.120) with respect to (3.124) gives us the following two first order conditions for the SC case:

$$c_{j,t+1} = \beta c_{j,t}(1 - \delta + p_{j,t}) \quad (3.127)$$

$$K_{p,j,t+1} = w_{j,t}K_{l,j,t} + (1 + p_{j,t} - \delta)K_{p,j,t} + (e_{j,t} - x)K_{e,j,t} + (r_{j,t} + \rho)K_{r,j,t} - c_{j,t} \quad (3.128)$$

and the transversality condition:

$$\lim_{t \rightarrow \infty} \beta_t \frac{k_{p,j,t+1}}{c_{j,t}} = 0 \quad (3.129)$$

Maximising (3.120) with respect to (3.125) and (3.120) with respect to (3.126) gives us the following three first order conditions for the CA case:

$$c_{1,t+1} = \beta c_{1,t}(1 - \delta + p_{1,t}) \quad (3.130)$$

$$c_{2,t+1} = \beta c_{2,t}(1 + \rho + r_{2,t}) \quad (3.131)$$

$$K_{p,1,t+1} = w_{1,t}K_{l,1,t} + (1 + p_{1,t} - \delta)K_{p,1,t} + (e_{1,t} - x)K_{e,1,t} + (r_{1,t} + \rho)K_{r,1,t} - c_{1,t} \quad (3.132)$$

$$K_{r,2,t+1} = w_{2,t}K_{l,2,t} + (1 + r_{2,t} + \rho)K_{r,2,t} + (e_{2,t} - x)K_{e,2,t} + (p_{2,t} - \delta)K_{p,2,t} - c_{2,t} \quad (3.133)$$

And the transversality condition:

$$\lim_{t \rightarrow \infty} \beta_t \frac{k_{p,j,t+1}}{c_{j,t}} = 0 \quad (3.134)$$

Details about the calculations are presented in appendix C. This concludes our presentation of the model. We now have all the equilibrium and definition equations to simulate our model. In the next section we present the scenarios and the results for the simulations.

III Simulations

In this section we present the results of the simulations of the model. After discussing the parametrisation, insisting notably on the current asymmetry in the distribution of wealth, we present simulations of the benchmark autarky model. The autarky model allows us to set a baseline for results regarding convergence in wealth without the possibility to trade. We then proceed to the assessment of convergence and sustainability in our two base scenario, CA and SC. In their presentation [Cuñat and Maffezzoli \(2004\)](#) defined a policy function to regroup the simulations of trade IE and CS equilibrium. Because of the different shapes of the functions in IE and CS, they end up using different sets of coefficients adapted to the polynomials of the policy function.

Our treatment of this issue is different. We start from the empirically more realistic situation of the CS equilibrium and study the dynamics of this equilibrium using shocks. We then force convergence to values compatible with FPE according to the FPE condition. This procedure produces counterfactual dynamics for capital stocks and prices, which likelihood can be compared to real world evolution in wealth. We then test the dynamics under FPE as a way to assess convergence. This strategy seems more adapted to our purpose of monitoring convergence, consumption, wealth levels and effective substitution under different trade settings. We believe it is the most realistic theoretical approach to trade and sustainability considering the evidence on “virtual sustainability” ([Atkinson et al. 2012](#)).

III.1 Parametrisation

[Cuñat and Maffezzoli \(2004\)](#) take α to be the average ratio of total trade to GDP for the US between 1947 and 2001. This gives a value of 0.15 for α . They choose the initial values for the

capital stock arbitrarily, and follow Cooley and Prescott (1995) for the parameters $\beta = 0.949$ and $\delta = 0.044$. The value of Φ is defined to yield a world produced capital steady-state equal to 1. Cheviakov and Hartwick (2009) examine at length the relation between technical progress and capital depreciation. Their scenarios imply a range of 0.0015 to 0.0444 for δ and a Solow neutral productivity term of 0.00384, although in a Cobb-Douglas function with three factors. The value for δ in Cuñat and Maffezzoli (2004) is slightly above the value tested by Cheviakov and Hartwick (2009) so we will use a value of 0.44.

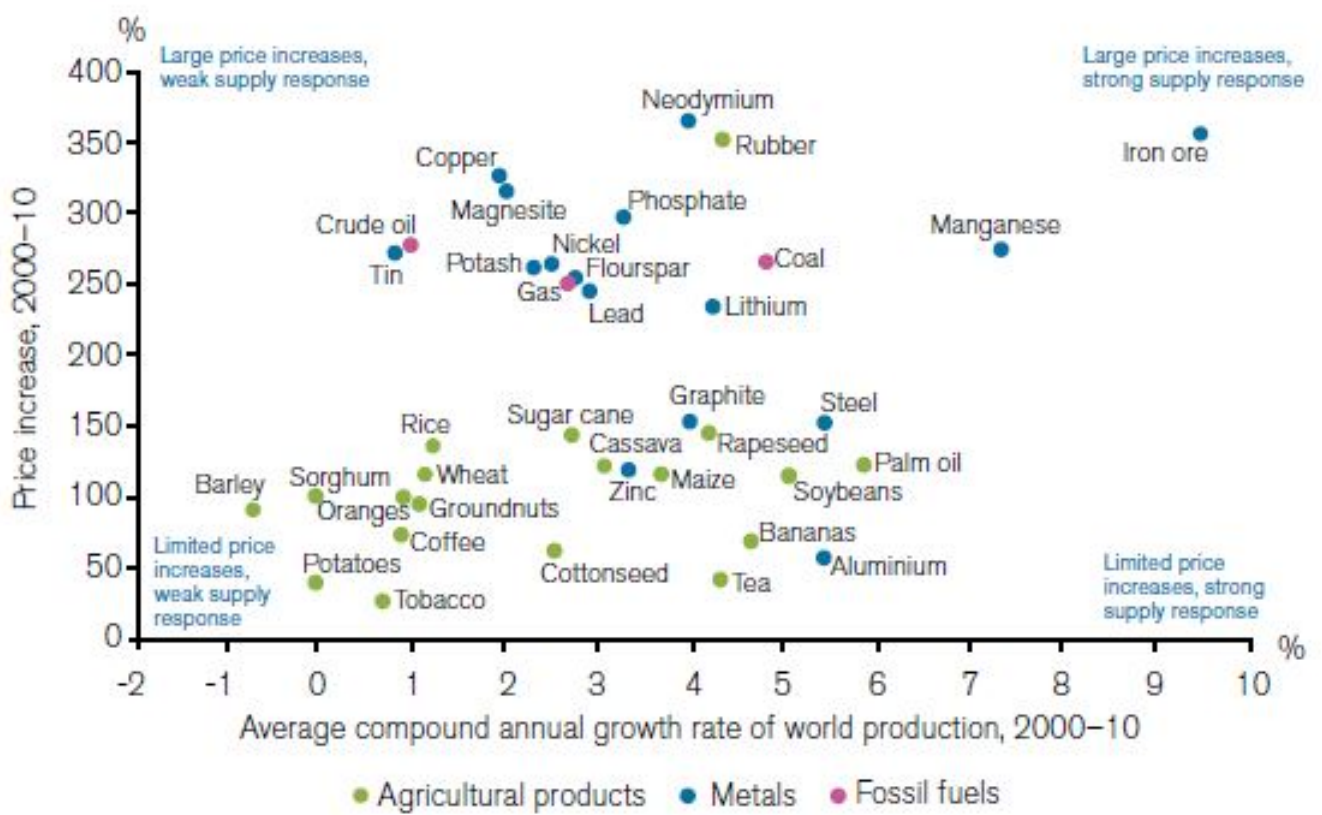
We will keep the same value for β . We know from the integrated equilibrium conditions that α balances factor endowments between goods x_1, x_2, x_4, x_5 and x_3 . In CS, the higher the value of α the greater the number of intermediates constituting the country's comparative advantage produced. We therefore keep the value introduced by Cuñat and Maffezzoli (2004), submitting it to sensitivity tests in the last subsection. Variations in the value of Φ result in less than proportional variations in the value of E . We will therefore set a value for Φ in the CS model under the SC scenario that yields a world steady-state level for produced capital equal to 2. Φ is set at 0.607.

Compared to those studies we have extra parameters. The price to pay for our modelling strategy centred on trade regimes is the lack of detailed modelling of the resources intensive sector. Finding an estimate for the parameter x boils down to estimating an aggregate cost function for the sector intensive in exhaustible resources. Cost functions are notoriously hard to estimate, especially in sectors using exhaustible resources as they have an obvious impact on the negotiations regarding royalties. Beyond this, geological parameters and size of the endowments matter. Our objective here is to conduct a simulation exercise centred on trade regimes. Back-of-the-envelope estimates of marginal extraction costs⁷ oscillate between 20% and 40% of the marginal product. In the IE model where we have a world price, this gives a value for x of 0.03 as 30% of total cost.

In a similar vein, the parameter ρ reflects the natural increase of the stock for a renewable resource. In a typical exhaustible resources model, the dynamics of the stock depend on several parameters. One of them is the rate of effort or stress put on the renewable resource by fishing, cutting down or harvesting. In our modelling strategy, ρ is the opposite to δ in the sense that it alleviates the maintenance cost of the stock. ρ is a bonus, equivalent to the marginal benefit of time. Every period, part of the resource grow to maturity without extra investment. The best proxy for this parameter would be the biological rates of growth for a range of renewable resources. However, those rates differ widely across species. Price responses are as a result inhomogeneous within and between exhaustible resources (Figure 3.4).

7. Commonly approximated with the average cost.

Figure 3.4: Growth rate in resources production with respect to price



Source: Chatham House report, p.53

Table 3.1: Parameter Values

α	0.15
β	0.949
δ	0.044
Φ	0.607
ρ	0.015
x	0.03

Source: Cuñat and Maffezzoli (2004), Author's calculations

Faced with this uncertainty we approximate the rate of growth using production data, assuming that an increase in production is based on the rate of biological renewal. The OECD and the FAO forecasts an average annual growth in net agriculture and fish production of 1.5%. We take this number for the value of ρ .

The values for Ξ and E are deduced from Φ and α :

$$\Xi = \frac{1}{(\Phi * (\frac{\alpha}{4})^\alpha * (1 - \alpha)(1 - \alpha))} = 3.095 \quad (3.135)$$

$$E = \frac{4^{(\alpha-1)}}{\Xi} = 0.099 \quad (3.136)$$

This concludes the presentation of the values assigned to our parameters. We will now discuss the distribution of endowments.

III.2 Asymmetric distribution in endowments and the scenarios

Debaere and Demiroglu (2003) conducted a thorough empirical examination of the violation of FPE. Their application is based on the Deardorff (1994a) “lens of diversification” test of factor intensity. The test itself is based on the difference between factor use, the needed factor flows to a given productive structure and factor endowments and the available flow in the country. The figures presented in Debaere and Demiroglu (2003) are rigorous in their attempt to amend raw input/output data for country differences in productivity and human capital. Table 3.2 displays the likelihood of FPE violation, understood as the superposition of the factor use and endowment lenses. The possibility of FPE for the world is ruled out. FPE is however very likely between OECD countries.

The evaluation of the factor content of trade in Atkinson and Hamilton (2002) follows a somewhat similar logic. The evaluation is based on domestic resource depletion to support

Table 3.2: Violation of FPE in Debaere and Demiroglu (2003)

Introducing measurement error

Country group	Adjustment	Dataset	Prob (Violation) (%)	Sigma	Measure	Measure with disaggregation
1 World	None	Mich	100.00	1.19	-0.82	-0.79
2 World	Hum. capital	UNIDO	98.55	1.08	-0.40	-0.36
3 World	Hum. capital	Mich	100.00	1.04	-0.94	-0.89
4 World	Prod. adj.	UNIDO	96.10	1.13	-0.16	-0.14
5 World	Prod. adj.	Mich	98.60	0.70	-0.50	-0.29
6 OECD	None	STAN	0.45	0.59	0.44	0.49
7 OECD	None	Mich	0.00	0.40	0.51	0.57
8 OECD	Hum. capital	UNIDO	1.10	0.48	0.37	0.44
9 OECD	Hum. capital	STAN	6.80	0.65	0.23	0.29
10 OECD	Hum. capital	Mich	0.05	0.46	0.49	0.53
11 OECD	Prod. adj.	UNIDO	0.20	0.51	0.53	0.55
12 OECD	Prod. adj.	STAN	16.25	0.68	0.13	0.20
13 OECD	Prod. adj.	Mich	0.00	0.45	0.50	0.54

Notes: The number of repetitions for each simulation is 2000. See Table 1 for the sources of the productivity adjustments.

Sigma: Average std. dev. of the log K/L ratios for sectors across countries as obtained from the data.

Measure: Positive if no violation of lens condition, negative if violation.

Measure with disaggregation: The new value of the measure when the lenses are adjusted for within-sector K/L variation.

Prod. adj.: With productivity-adjusted labor and capital, based on factor awards relative to the US.

Human capital: After adjustment for differences in human capital, proxied by differences in return to education.

Source: *Debaere and Demiroglu (2003), p.118*

a given level of output. This highlights for the difference we mentioned in the introduction between the potential meaning of factor use. When exhaustible resources are involved factor use matters against the needed optimal depletion of resources in a dynamic (intergenerational perspective). Even if the accounting framework use is in essence static, the reasoning and the rationale for the assessment is dynamic. Usual exercises regarding factor content are not concerned with exhaustible resources and do not face this hurdle.

Taking those remarks into account leads us to conclude that, under the important reservation of an added production pattern⁸, the distribution of wealth components (stocks) gives an indication of the nature of the flows (endowments) in the economy and so of the likelihood of FPE. Comprehensive wealth is an indicator of specialisation through endowments derived from it, in line with the Heckscher-Ohlin theorem.

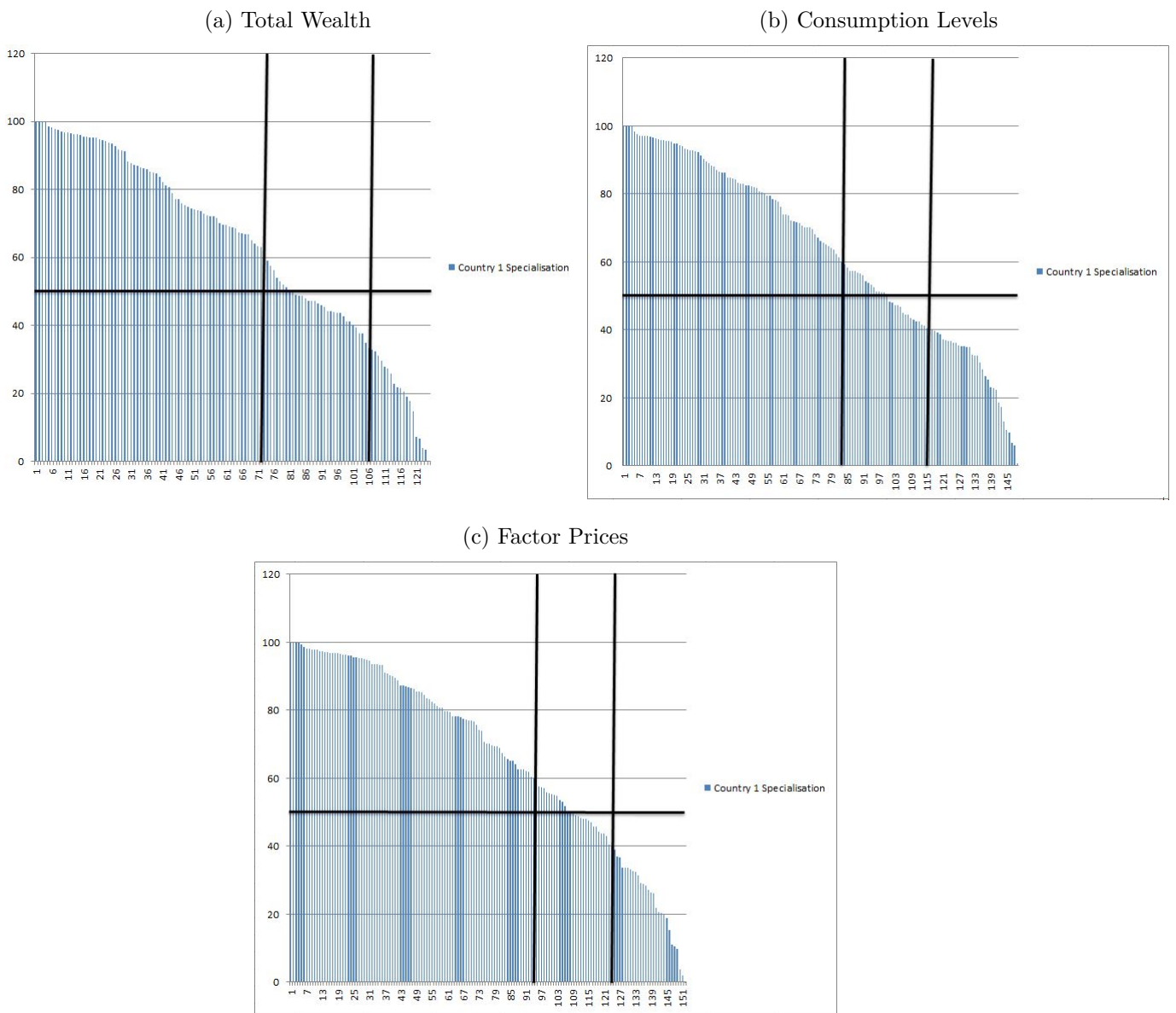
To obtain the predicted dispersion, we extract comprehensive wealth data from the World Bank⁹ database. All data are in constant 2000 US dollars and available in three waves: 1995, 2000 and 2005. We then divided total wealth into four components. Produced capital K_p is obtained directly from the produced capital column. Exhaustible resources K_e is the sum of subsoil assets and renewable resources K_r is the sum of crop, forestry and pasture lands. Intangible capital is decomposed using the 2000 estimate of the average share of human capital (skilled and unskilled labour) in intangible capital by the World Bank (2006). It should be noted that this is an average, and that the share of labour in intangible capital is likely to be higher in less advanced countries (low income) than in more advanced ones (middle and high income). In terms of asymmetry in endowments, this means that the comparative advantage in labour is likely to be overestimated from intangible capital. Labour (human capital for the World Bank) K_l is assumed to be 36% of intangible capital for all countries.

The results of the decomposition are available in appendix D for the three waves in 1995, 2000 and 2005. A selection is displayed in table 3.3. To position countries in terms of comparative advantage, we consider a comparative advantage in exhaustible resources (renewable and non renewable) on the one hand, and a comparative advantage in labour and produced capital on the other hand. The distribution of specialisations is quite telling. Figure 3.5 shows the distribution of countries for the three waves. Countries are ranked in terms of country 1 type comparative advantage, that is weight of labour and produced capital in total wealth. We add on those diagrams the 50% factor intensity reversal line. We also add two lines indicating the number of countries satisfying the indicative FPE condition under our parametrisation (see appendix D).

8. A production structure associated with amendments for productivity, etc. A production structure is implicit in wealth accounting as production functions are used to construct wealth estimates.

9. See <http://databank.worldbank.org/data/home.aspx>.

Figure 3.5: Distribution of Countries in wealth



Source: *The World Bank wealth accounting database, Author's calculations*

Table 3.3: Capital stock shares in comprehensive wealth

Country	Country 1 Specialisation			Country 2 Specialisation			FPE		
	1995	2000	2005	1995	2000	2005	1995	2000	2005
Australia	87.2940471	84.2604816	86.2496896	12.7059529	15.7395184	13.7503104	No	No	No
Canada	86.3054385	84.706197	86.6271915	13.6945615	15.293803	13.3728085	FPE	FPE	FPE
Cameroon	54.0782139	51.3426453	53.5090651	45.9217861	48.6573547	46.4909349	No	No	No
France	96.2096665	94.8192153	96.8764731	3.7903335	5.18078467	3.1235269	FPE	FPE	FPE
Germany	97.6356442	96.6146916	97.8126273	2.36435578	3.38530836	2.18737265	No	No	No
Gabon	51.306419	36.1529162	33.1943701	48.693581	63.8470838	66.8056299	FPE	FPE	FPE
Iran, Islamic Rep.	47.318638	36.9396631	40.0445353	52.681362	63.0603369	59.9554647	No	No	No
Russian Federation	N/A	41.485027	45.8184628	N/A	58.514973	54.1815372	FPE	FPE	FPE
Saudi Arabia	37.775119	40.4626837	26.3827497	62.224881	59.5373163	73.6172503	No	FPE	No
United Kingdom	97.0659405	97.1791225	97.908853	2.93405951	2.82087747	2.09114702	FPE	FPE	FPE
United States	95.2206733	95.3549561	95.9313002	4.77932672	4.6450439	4.06869978	No	No	No
							FPE	FPE	FPE

Source: The World Bank wealth accounting database, Author's calculations

In line with [Debaere and Demiroglu \(2003\)](#) results, wealth shows a distribution that is strongly asymmetric in subcomponents. Beyond the level of wealth, it is the distribution of the sources of wealth that will impact specialisation. We find here a confirmation of the unlikelihood of world FPE in the context of exhaustible resources. Exhaustible resources abundant countries appear to be less numerous overall, but more of them fulfil the FPE condition. More strikingly, the divide is not between OECD countries on one side of this specialisation and the rest of the world on the other. High income countries are all at the very right end of the divide. On both sides of the 50% can be found developing countries such as Vietnam, Cameroon or Côte d'Ivoire. Those results are a confirmation that global trade liberalisation under FPE is impossible, but that regional free trade agreements might result in FPE.

The FPE condition in our model is defined by the equality $K_1^{FPE} = \frac{1}{2}K_l + \alpha K_l = (\frac{1}{2} + \alpha)K_l$. Every factor endowment in both countries should stay below the level K_1^{FPE} for FPE to occur. Since the level and composition of wealth is one of our main objects of interest, we test our model for a broad range of endowment distribution instead of calibrating the model for a given pair of economies. With $\alpha = 0.15$ and each country endowed with one unit of capital, FPE breaks down for an asymmetry above $\frac{0.70}{1.3}$ in exogenous endowments. Table 3.4 shows a random distribution of wealth where FPE is violated for values above 1.19. As capital accumulates or de-cumulates, the threshold varies accordingly.

Table 3.4: Assessment of the FPE condition

	kl	kp	ke	kr	Total
Country 1	1.31	0.98	0.69	0.69	3.67
Country 2	0.69	0.78	1.31	1.31	4.09
Total	2	1.76	2	2	7.76
FPE	1.3	1.144	1.3	1.3	

Source: Author's calculation

III.3 The autarky model

Before proceeding to the test of trade regimes, we set-up the autarky version of our model as the reference for the results of the trade models. As presented above, the autarky case is in fact the trade model with $\alpha = 0$. As there is no trade between the two countries they will both produce only intermediate good y_3 as a way to maximize utility, as shown by taking $\alpha = 0$ in equation 3.1. This will result in the equivalent of a standard neoclassical growth model with four factors of production and one final good. This conclusion has important consequences for our results. In the autarky model the productivity coefficient affecting factor prices is $\frac{\Phi}{4}$. In the IE model factor prices are equalised and the coefficient takes the value E . Finally, under CS, factor prices differ across countries and the productivity coefficient is also E .

One can easily observe from equations 3.135 and 3.136 that $\frac{\Phi}{4} > E$ for any value of Φ and α . An economic rationale for this feature of the model can easily be found in the higher coordination costs in an economy with five intermediates, compared to an economy with only one. But this leaves open the question of the *raison d'être* of intermediate goods in the first place. In an HO model, trade is motivated by differences in endowments and the production structure reflects this with the intermediate goods. Each of those is exclusively produced using one endowment creating the possibility to exploit the comparative advantage. The rationale for intermediate goods in our model is trade, and it is sensible that under autarky only one intermediate is produced, making *de facto* production equivalent to a single final good case. The development of the global supply chain (Berger 2006) is a case in point that international trade translates into a more complex production structure.

The dynamic component in autarky is the same as under free trade:

$$c_{j,t+1} = \beta c_{j,t}(1 + p_{j,t+1} - \delta) \tag{3.137}$$

$$Kp_{j,t+1} = w_{j,t}Kl_{j,t} + (1 + p_{j,t} - \delta)Kp_{j,t} + (e_{j,t} - x)Ke_{j,t} + (r_{j,t} - \rho)Kr_{j,t} - c_{j,t} \tag{3.138}$$

The maximisation of production yields the following first order conditions for factor prices:

$$w_{j,t} = \frac{\Phi K e_{j,t}^{\frac{1}{4}} K p_{j,t}^{\frac{1}{4}} K r_{j,t}^{\frac{1}{4}}}{4 K l_{j,t}^{\frac{3}{4}}} \quad (3.139)$$

$$p_{j,t} = \frac{\Phi K e_{j,t}^{\frac{1}{4}} K l_{j,t}^{\frac{1}{4}} K r_{j,t}^{\frac{1}{4}}}{4 K p_{j,t}^{\frac{3}{4}}} \quad (3.140)$$

$$e_{j,t} = \frac{\Phi K e_{j,t}^{\frac{1}{4}} K p_{j,t}^{\frac{1}{4}} K r_{j,t}^{\frac{1}{4}}}{4 K e_{j,t}^{\frac{3}{4}}} \quad (3.141)$$

$$r_{j,t} = \frac{\Phi K e_{j,t}^{\frac{1}{4}} K l_{j,t}^{\frac{1}{4}} K p_{j,t}^{\frac{1}{4}}}{4 K r_{j,t}^{\frac{3}{4}}} \quad (3.142)$$

We use the autarky model to present our procedure. We first inquire about the consequences of asymmetry in endowments between the two countries. To this end, we produce diagrams with the evolution of the steady-state as a function of increasing asymmetry in our exogenous endowments¹⁰ for wealth, consumption, produced capital and factor prices. We denote in the rest of the chapter a situation of asymmetry in exogenous variables the following way. $k = 1.20$ means that the distribution of exogenous variables is $K_{l,1} = 1.2, K_{e,1} = 0.80, K_{r,1} = 0.8, K_{l,2} = 0.8, K_{e,2} = 1.2$ and either $K_{p,2} = 0.8$ in CA or $K_{r,2} = 1.2$ in SC for country 2.

We then present the motion from a high asymmetry steady-state to a low asymmetry one. The high asymmetry equilibrium is $k = 1.75$ and the low asymmetry one is $k = 1.19$, the highest values compatible with FPE for all endowments in the SC scenario¹¹. In the high asymmetry case, the less abundant endogenous factor represents 14% of the more abundant one and in the low asymmetry case 68%¹². We saw above that only 28 countries in 2005 could be considered in a state compatible with the low asymmetry steady state¹³. This comparison will give us a sense of the size of the adjustment required, in terms of factor prices and capital stock evolution to reach the area of theoretical convergence in steady-state consumption. In the settings allowing trade, the high asymmetry equilibrium produces CS, while the low asymmetry equilibrium produces IE in SC.

10. (K_l, K_e and K_r in SC, K_l, K_e and K_p in CA for country 2).

11. As it will be presented below, FPE never occurs in CA.

12. The difference between the endogenous factor and the exogenous one is here critical. Although the distribution of exogenous factors yield a less stringent FPE condition at $k = 1.29$, the endogenous one, because of the difference in accumulation rate between the two countries sets a more stringent rule at $k = 1.19$.

13. This conclusion is obtained by setting a FPE condition based on the sum of produced capital and labour on the one hand and exhaustible resources on the other hand. We add factors two by two to obtain an approximation of the likelihood of FPE as we cannot know which factor will lead to a break down in FPE first. The figure is therefore to be understood as a lower bound.

We then assess the consequences around the steady state of shocks on our exogenous endowments. We define four scenarios as the framework for the shocks:

Scenario 1: country 1 experiences an increase in population size : temporary increase in its comparative advantage.

Scenario 2: country 2 experiences an increase in population size: temporary increase of an endowment outside of its comparative advantage.

Scenario 3: country 1 experiences a increase in exhaustible resource stock size: temporary increase of an endowment outside of its comparative advantage.

Scenario 4: country 2 experiences a decrease in exhaustible resource stock size: temporary depletion of a source of comparative advantage.

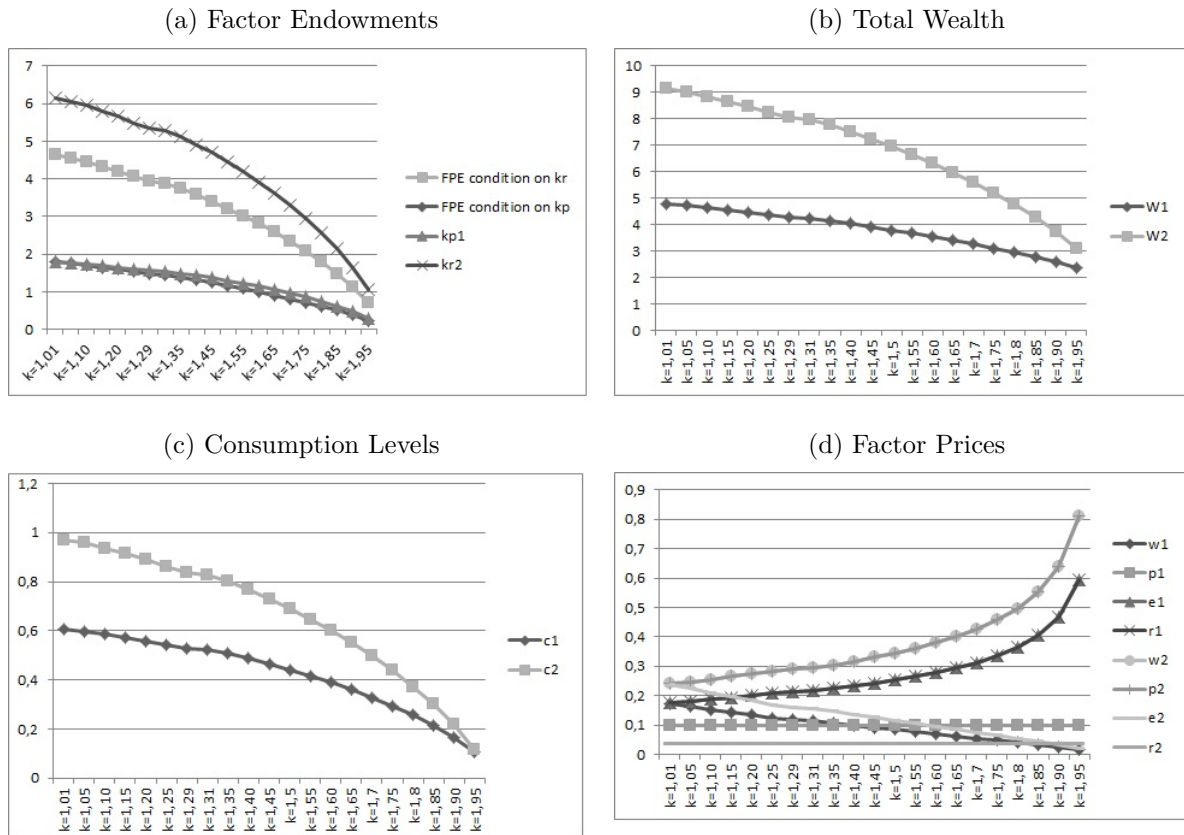
We compare the results of those shocks on both countries under CA and then SC. The difference in the productivity parameter between autarky and the two free trade settings makes it impossible to compare the size of the shocks. We therefore only compare levels across the three models and magnitude between IE and CS. Finally, we assess the likelihood of convergence in consumption at the steady-state and the size of the adjustment required to reduce consumption gaps between countries. We test those shocks under the transitional dynamics as a way to see how the shock fits in a broader adjustment.

It should be noted that the relevant transitional dynamic is used. Hence scenarios implying an increased asymmetry in endowments forming the comparative advantage are assessed in the context of convergence from low to high asymmetry, so that consumption and wealth are on a downward trend. Conversely, a shrinking comparative advantage is assessed in the context of reduction from high to low asymmetry in endowments. To run the simulations, we use the Dynare software (Adjemian et al. 2011). Dynare is a powerful solution to provide numerical solutions for both deterministic and stochastic general equilibrium models. We run the model using our main, benchmark parametrisation, described above.

III.4 Trade simulations

We saw in chapter 2 that “trade optimists” defended trade liberalisation on efficiency grounds. Should this perspective be vindicated, then going from autarky to free trade would have positive effects on wealth and consumption levels. In this section we compare autarky, the integrated equilibrium (IE) and the complete specialisation equilibrium (CS) under both comparative advantage (CA) and structural change (SC) patterns of accumulation. Those simulations form the basis of our analysis on the relative merits of autarky and free trade in terms of both levels and dynamics of wealth and consumption

Figure 3.6: Constrained steady-state values under CA in autarky



Source: Author's calculation

III.4.1 Simulations under the comparative advantage (CA) case

Under the comparative advantage scenario, both countries invest and maintain different factor endowments as they focus on the factor providing their comparative advantage. The notion of comparative advantage makes obviously little sense under autarky, but is the natural basis for comparisons with free trade.

The evolution of constrained steady state-values under CA in autarky are presented in figure 3.6. We observe no convergence in consumption across the steady-states constrained by asymmetry. It is however notable that steady-state levels of consumption are getting closer as asymmetry increases¹⁴. Endogenous capital stocks are decreasing with asymmetry but in a much steeper fashion for country 2. In country 2 wealth decreases by 38% with asymmetry, while in country 1 the fall is only 30%. Produced capital is down 48% in country 1 and renewable resources decrease by the same amount in country 2.

14. With consumption in country 1 67% of consumption in country 2 for the high asymmetry equilibrium.

Movements in wealth and consumptions can be explained by domestic factor prices. The price of the endogenous capital stocks is constant across specifications at 0.977 for K_{p1} and 0.038 for K_{r2} . Hence the prices of the factors not constituting the comparative advantage (e_1, r_1, w_2, p_2) increase rapidly while the price of the “complementary” factors¹⁵ w_1 and e_2 decrease. As a result of our production structure, the non comparative advantage factors move together, so $w_2 = p_2$ and $e_1 = r_1$. The spread $\frac{w_2}{r_2}$ goes from 7.01 to 11.81 with asymmetry and the spread $\frac{r_1}{p_1}$ goes from 2.04 to 3.43 with asymmetry. In the meantime the spread $\frac{e_2}{r_2}$ goes from 4.51 to 1.68 with asymmetry and the spread $\frac{w_1}{p_1}$ goes from 1.31 to 0.49 with asymmetry.

As endowments grow more asymmetric, the exogenous factors become relatively abundant (scarce) with respect to the endogenous ones when they are (not) the source of the comparative advantage. The price increase in dwindling resources is not enough to compensate the fall in the price of the increasingly abundant resources, resulting in shrinking consumption and (via shrinking investment) wealth. The relative reduction in wealth and consumption is greater for country 2 as its comparative advantage factor yields a discount on the maintenance cost. Under our benchmark parametrisation this discount is non trivial with a discount of 4.4% on produced capital and a bonus of 1.5% on renewable resources. Hence one unit less of renewable resources is a higher opportunity cost for country 2 than one unit less of produced capital for country 1.

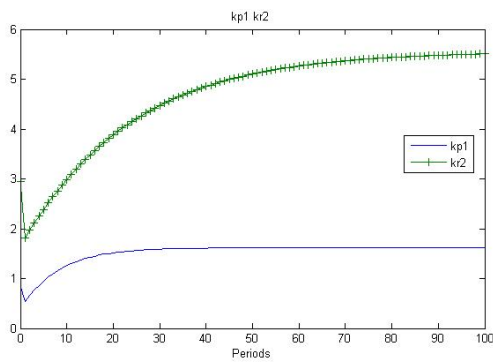
We proceed with the assessment of the transitional dynamics under a permanent shock, moving from high to low asymmetry in exogenous endowments. Results are displayed in figure 3.7. The transition requires 262 periods to be complete, although the bulk of the adjustment happens in the first 100 periods.

The two steady-states bounding the transitional dynamics are going to be the boundaries of our studies on shocks. In CA, there is no level of asymmetry for which FPE will occur as endogenous capital stocks are too different when exogenous endowments are close enough. As a consequence the low asymmetry constrained steady-state is used mostly for comparison purposes. Transition from the high asymmetry to the low asymmetry steady-state requires a 32% reduction in the abundant exogenous factor endowment and a 224% increase in the scarce exogenous factors in both countries. As a result of this quite large exogenous shock, consumption increases by +90% in country 1 and +104% in country 2. This is paid for via a 92% increase in produced capital in country 1 and the same 92% increase in renewable resources in country 2. The overall impact on wealth is an increase of 43% for country 1 and of +63% in total wealth for country 2. As for factor prices, e_1, r_1, w_2 and p_2 are all reduced by 40% in the transition while w_1 and e_2 increases by 183%, p_1 and r_2 being stable.

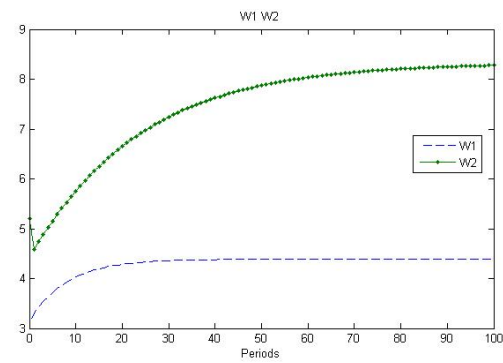
15. That is to say the other factor forming the comparative advantage of the country.

Figure 3.7: Transitional dynamics under CA (permanent shock)

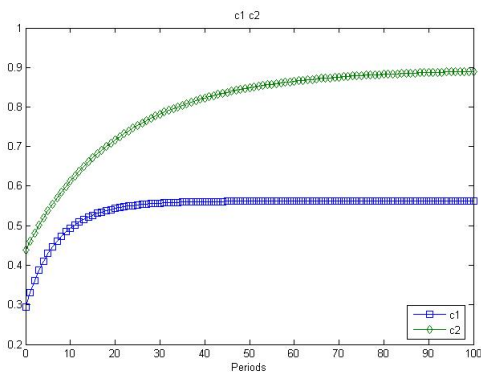
(a) Factor Endowments



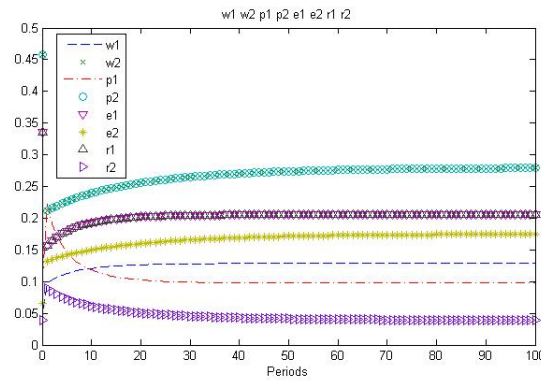
(b) Total Wealth



(c) Consumption Levels



(d) Factor Prices



Source: Author's calculation

The adjustments involved are very large, reflecting the size of the shock on exogenous variables. Achieving an adjustment this size internally is certainly not easy, although the timing of the adjustment suggests a quite long time span of roughly 100 periods for the bulk of the adjustment. The transition profile is also interesting. Consumption increases steadily from the beginning, faster in country 1 than in country two, although the increase also stops much faster: the bulk of the adjustment is made after only 25 periods. The endogenous capital stocks both drop sharply in period one before increasing steadily with again a much quicker adjustment in country 1. As the shock on exogenous variables is applied at once in period one, wealth follows the same pattern. Neither do prices adjust smoothly. All the varying prices overshoot in period 1, i.e. increasing or decreasing by more than their steady-state level, before converging slowly in around 70 periods.

The nature of the adjustments in the model is quite close to the real life necessities of development. Reducing asymmetry in endowments implies substitution between the components of the productive base. This rate of substitution is determined by factor prices and occur in the form of money-substitution as in the Hartwick rule. We described how an increase in consumption requires for country one to reduce its over abundance in labour while increasing its stocks of produced and natural capital. Country two increases its endowments in all factors except exhaustible resources.

The behaviour of country 2 fits the story of the Hartwick rule, substituting produced capital for exhaustible resources. It adds to the Hartwick rule the need to foster a potential source of comparative advantage, renewable resources. As for country 1, while it may make sense for labour, produced capital and renewable resources to increase, an increase in exhaustible resource is subject to discoveries and exploration costs. Substituting produced capital for labour makes perfect sense for country 1, but rebalancing its components of wealth may prove harder. Increases of natural capital in country 1 will more likely come from renewable resources than exhaustible resources, underlying the limits of our assumption of symmetry in the use of intermediates.

Another fact seems puzzling at first hand. Going from high asymmetry to low asymmetry requires the build-up of the stock of factors which price is decreasing in the process and vice-versa. This feature comes again from our production structure where all inputs enter equally in production in autarky. This result simply expresses the need to make more of some factors available for production to increase output and consumption. The lost income from cheaper factors is more than compensated by the extra consumption made possible via the extra income and the extra income from the less abundant factor. Our production structure therefore suggests that when all inputs are required in the production process it is rational to give up on

higher return from some factors if a more equal distribution of factors allows for more efficient production. We will see how free trade affects this feature below.

Our model yields intuitive strategies for both countries, in line with the sustainability literature. The framework being consistent with observed facts, it seems fit to test in the context of real world experiences, embodied in our scenarios. We test the four scenarios as temporary shocks affecting both countries in steady-state. Temporary shocks are an interesting way to introduce exogenous accumulation and depletion constraints on the endogenous accumulation process in both countries. We fit the scenario in the relevant broader transition path. For example, if the shock implies as in scenario 1 that the country is in fact drifting from a low asymmetry steady-state to a high asymmetry steady-state, we “nest” the temporary shock between the constrained steady states $k = 1.19$ and $k = 1.75$.

To decide on the size of the shock, we use the data on comprehensive wealth. We use 2000 as the reference year since we based our decomposition of intangible capital on it. For the shocks on labour, we look at the sample of countries under FPE in 2000 and we take those with a northern specialisation. This is a sample of 16 countries¹⁶. We then compute the variation for the same countries in 2005. The data exhibits strong cross country variations, for an average increase in labour of 10%. This figure is subject to the strong assumptions we made earlier regarding the decomposition of intangible capital. We use this number as the order of magnitude, increasing or decreasing the exogenous labour endowment by 10% over 30 periods. We take this value of 30 periods since it is the third of the period required for the bulk of the adjustment in the transitional dynamics.

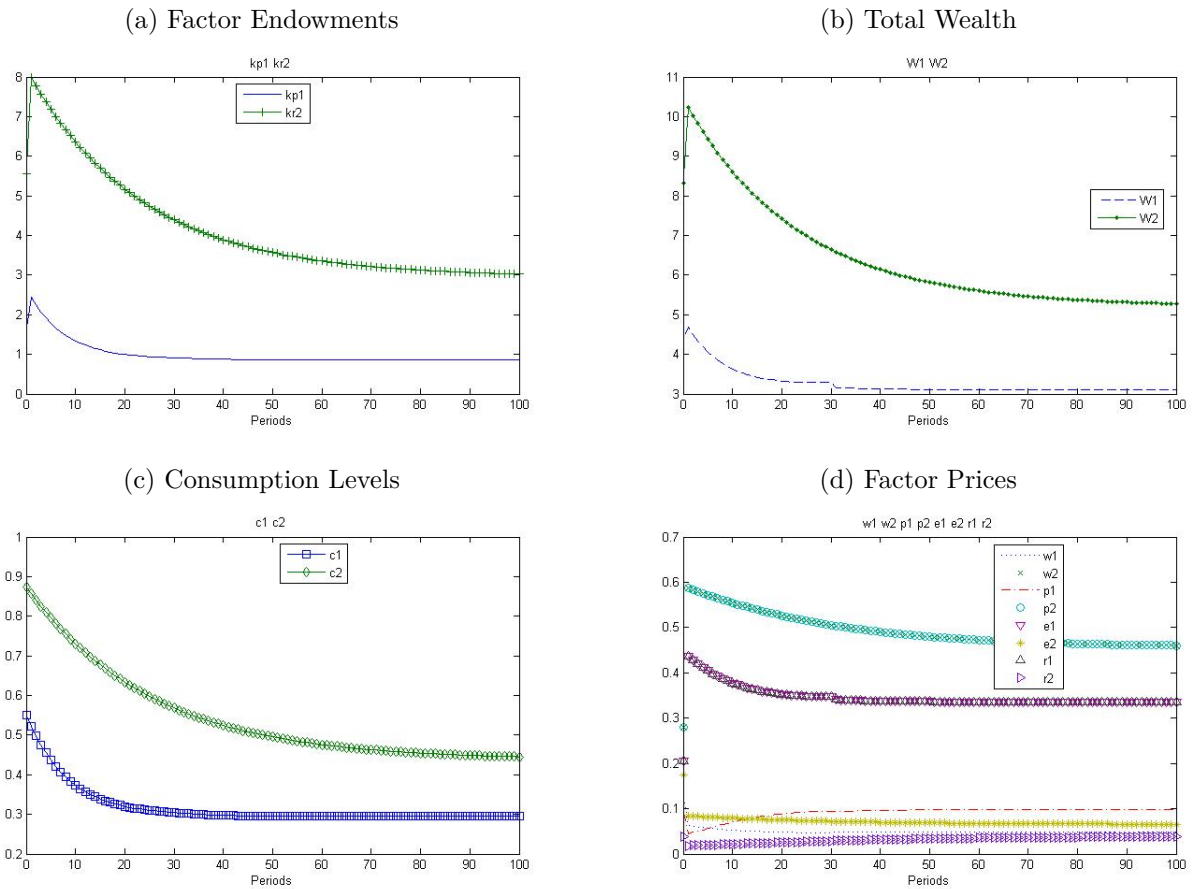
Scenario 3 and 4 require a similar magnitude for the non renewable component of natural capital. We use a similar method taking (as in those scenarios the economy converges towards low asymmetry) the evolution between 2000 and 2005 of exhaustible non renewable resources in countries with a country two specialisation without FPE. This yields a sample of 30 countries¹⁷, shortened to 13 to remove zeros and aberrant values. The average variation is this time 23%, which we take as our shock value, spread over 30 periods.

The results for scenario 1 are displayed in figure 3.8. Convergence from the low asymmetry to the high asymmetry equilibrium is marked by initial overshoot in wealth and produced capital. The first impact of the temporary shock is to set wealth on a higher convergence trend which dies down rapidly when the shock fades. The shock translates into a 6.15% increase

16. It is interesting to note that the same criteria yields the exact same sample size for 2005, but only 4 countries are left from 2000.

17. The 2005 sample is composed of 28 countries and the two samples have 18 common values, suggesting more stability in country-two specialisation without FPE.

Figure 3.8: Scenario 1 under CA (temporary shock)



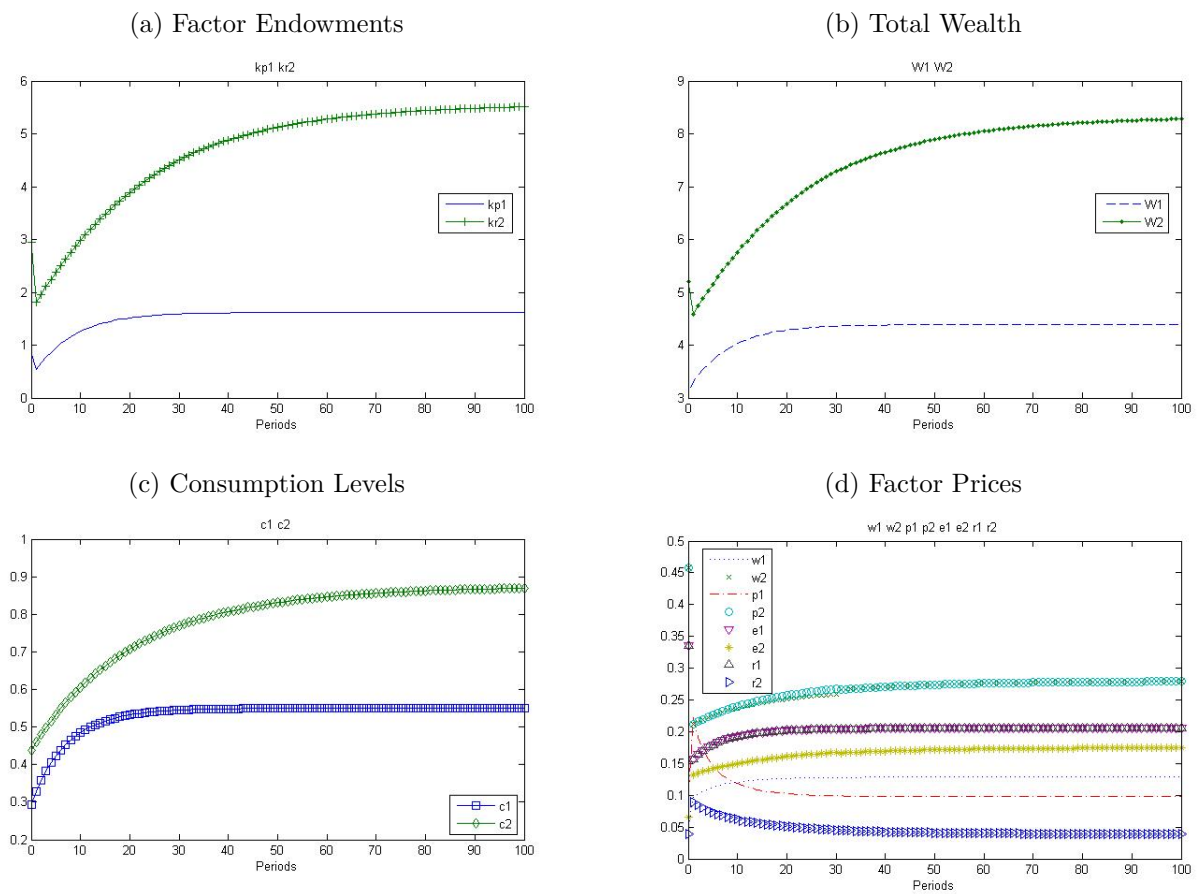
Source: Author's calculation

in the world stock of labour, and a 1.44% increase in total wealth. Country one witnesses a 1.4% increase in consumption 4.5% increase in wealth and a 2.19% increase in produced capital compared to the regular convergence path. As for prices, e_1 and r_1 both increase by 2.26% with p_1 increasing by 0.07% and w_1 shrinking by 4.45%. The largest impact are therefore on wealth and the price of labour, with a notably larger impact on produced capital than consumption. Reallocation of resources in the face of a positive shock is biased towards investment.

Scenario 2 represents a 1.24% increase in the global endowment of labour. Under scenario 2, country 2 sees its consumption increased by 0.55% at the peak of the shock against the regular trend. Wealth increases by 0.82% and renewable resources by 0.77%. Prices impacts are also larger than under scenario one with p_2 and e_2 increasing by 0.99% and r_2 by 0.21% while w_2 is down 2.16%.

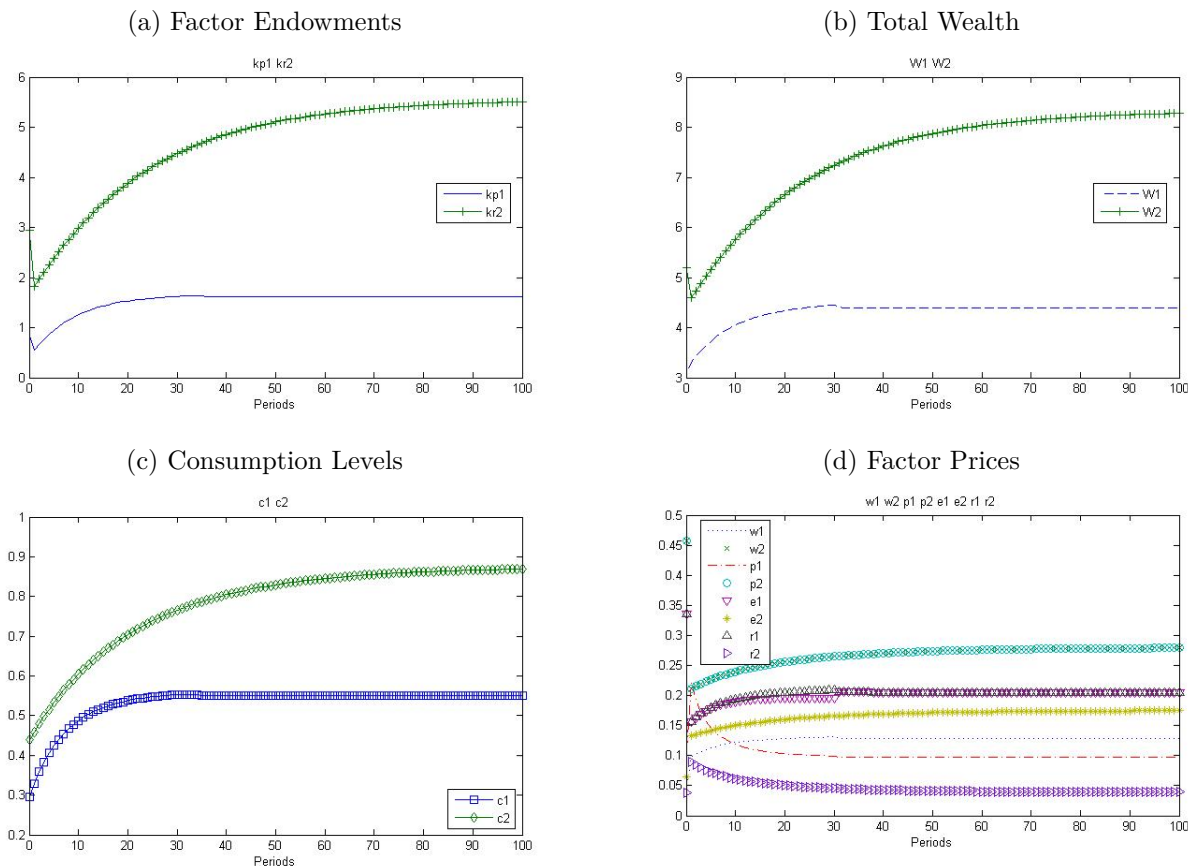
Under scenario 3 (figure 3.10), global exhaustible resources raised by 2.86%. Consumption in country 1 increases by 1.44%, wealth by 2.14% and produced capital by 2.26%. As for

Figure 3.9: Scenario 2 under CA (temporary shock)



Source: Author's calculation

Figure 3.10: Scenario 3 under CA (temporary shock)



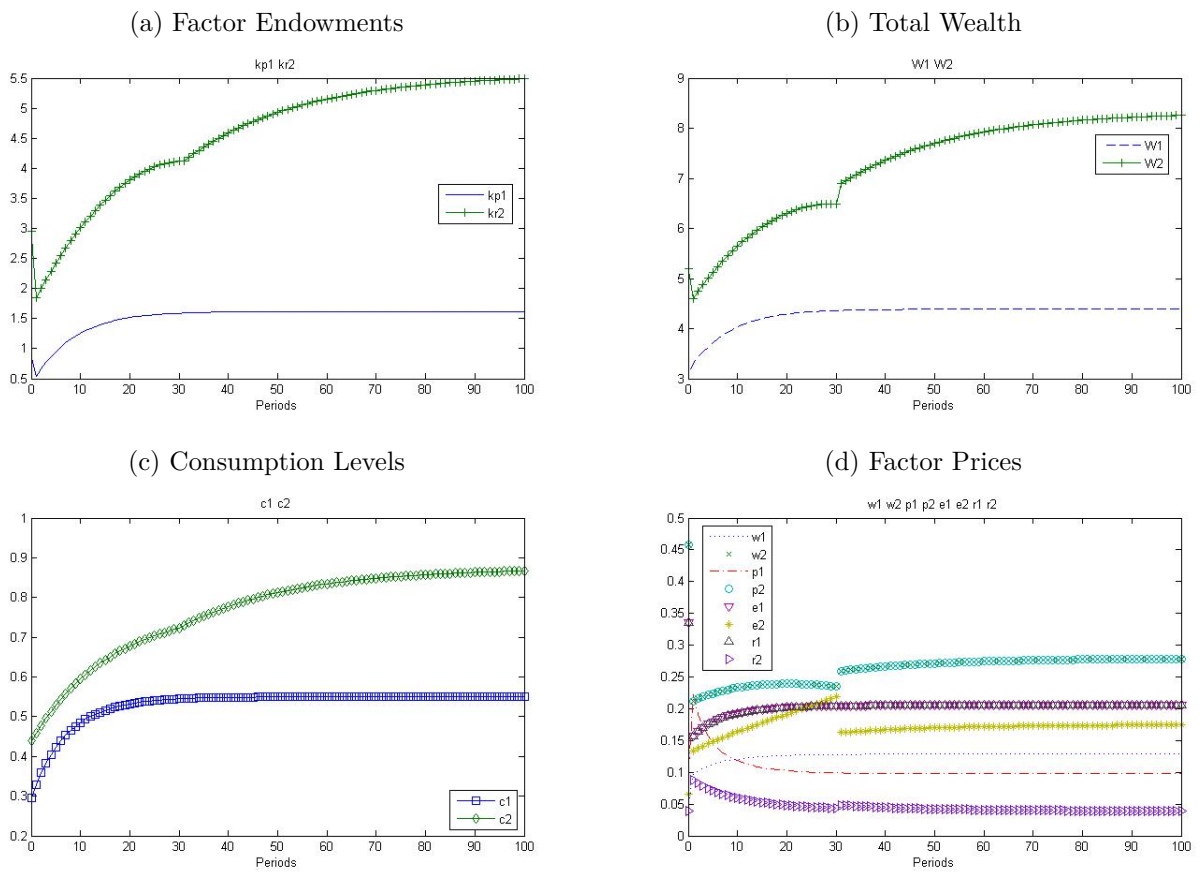
Source: Author's calculation

prices, w_1 increases by 2.38% relative to the regular trend, p_1 by 0.11%, r_1 by 2.38% while e_1 is reduced by 4.7%. Scenario 3 pictures an exogenous reduction in asymmetry from a high asymmetry equilibrium. It is striking that the consumption gains are barely higher than in scenario 1 although the shock is larger. This is first evidence that the starting point and the implicit direction of adjustment matters as much as the size of the shock.

Finally, scenario 4 (figure 3.11) shows the impact of a resource depletion shock, which are much higher than those implied by the addition of the same amount in scenario 3 for country 1. Under scenario 4, consumption shrinks by 5.55% in country 2 compared to the regular transitional dynamics, wealth by 10% and renewable resources by 7.8%. Price adjustments are also relatively important with w_2 and p_2 reduced by 11.2% and r_2 by 3.71%. Exhaustible resources price in country 2 rises by one third (31%) suggesting a more than proportional reaction.

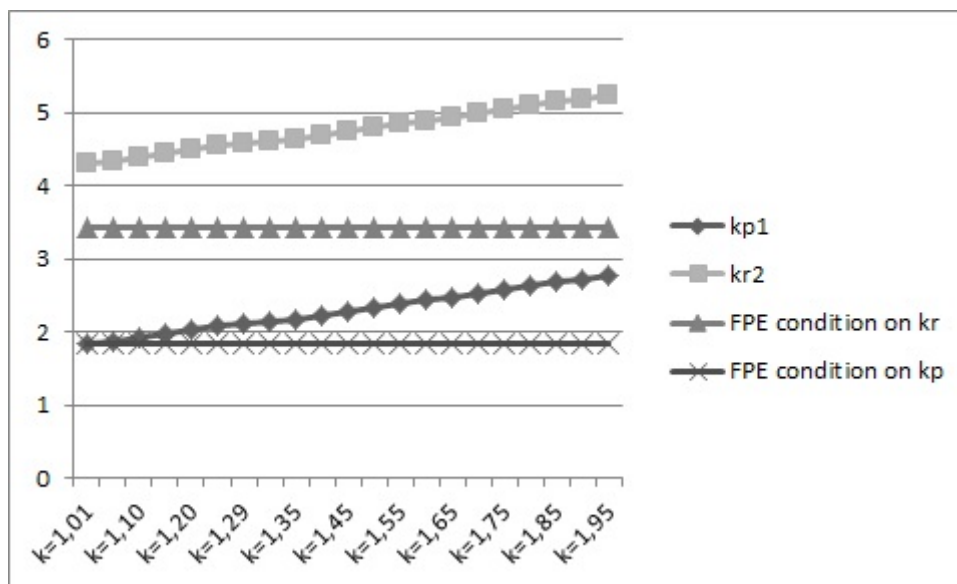
This concludes our presentation of the autarky model and scenarios. The autarky model gives us a basis against which the results of the free trade simulations can be assessed. The

Figure 3.11: Scenario 4 under CA (temporary shock)



Source: Author's calculation

Figure 3.12: Endogenous endowments and FPE in IE



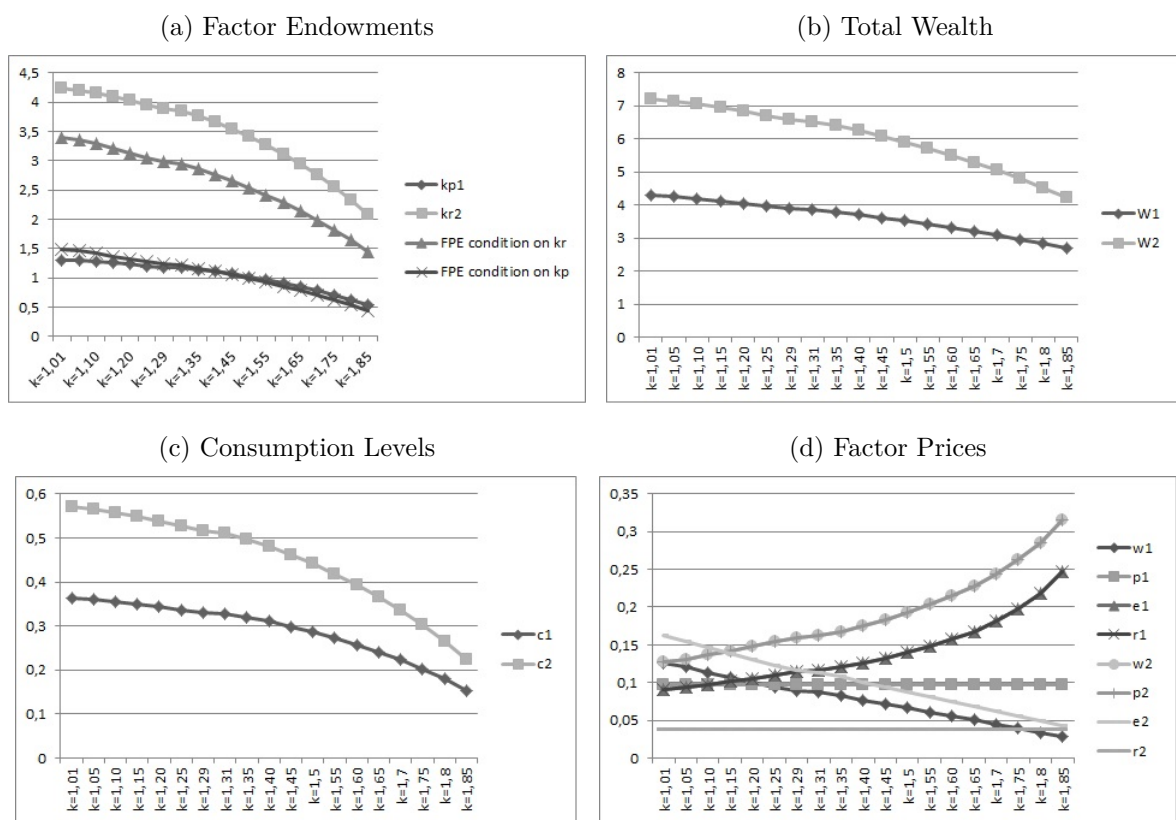
Source: Author's calculation

CA case yields a distribution of endogenous capital stocks that is incompatible with FPE for any distribution of exogenous endowments. As a result, trade-liberalisation in CA never yields the integrated equilibrium (see figure 3.12). This result is confirmed by the assessment of the FPE condition in the CS equilibrium. FPE is also violated for any asymmetry in exogenous endowments, at least for $K_{r,2}$ (see figure 3.13a). As a result, we only compute the trade equilibrium under CS. The distribution of constrained steady-states with asymmetry is presented in figure 3.13.

The dynamics under CS are similar to autarky. Both endogenous endowments are decreasing with asymmetry, with Kp_1 decreasing by 42.5% and Kr_2 decreasing by 37%. Those figures are significantly lower than under autarky. Consumption in country 1 is reduced by 41% with asymmetry, compared to 47% in autarky. Those values are 44% and 51% respectively for country 2. As for convergence in consumption, going from autarky to free trade has virtually no effect. In autarky country 1 consumption goes with reduced asymmetry from 63% to 67% of country 2 consumption. Under free trade those numbers are respectively 64% and 67%.

Opening-up to trade has a stronger effect on prices. Non comparative advantage factors are still moving together, with $w_2 = p_2$ and $e_1 = r_1$. The spread $\frac{w_2}{r_2}$ goes from 3.78 to 6.77 with asymmetry and the spread $\frac{r_1}{p_1}$ goes from 1.07 to 2.01 with asymmetry. In the meantime the spread $\frac{e_2}{r_2}$ goes from 3.39 to 1.45 with asymmetry and the spread $\frac{w_1}{p_1}$ goes from 1.04 to 0.40 with asymmetry. Still exogenous factor prices are lower under free trade than under autarky.

Figure 3.13: Constrained steady-state values in autarky



Source: Author's calculation

Free-trade creates a stronger reaction with prices rising and falling faster than under autarky. Those findings on prices combined with the evolution of our variables of interest lead us to conclude that the difference in the production structure introduced between autarky and free trade diminishes further the returns to scale. As endowments are now to be split between three different intermediate sectors in each country, a similar shock on the overall endowment distribution will lead to stronger price responses as the effect on each individual sector is more than the shock on the overall structure.

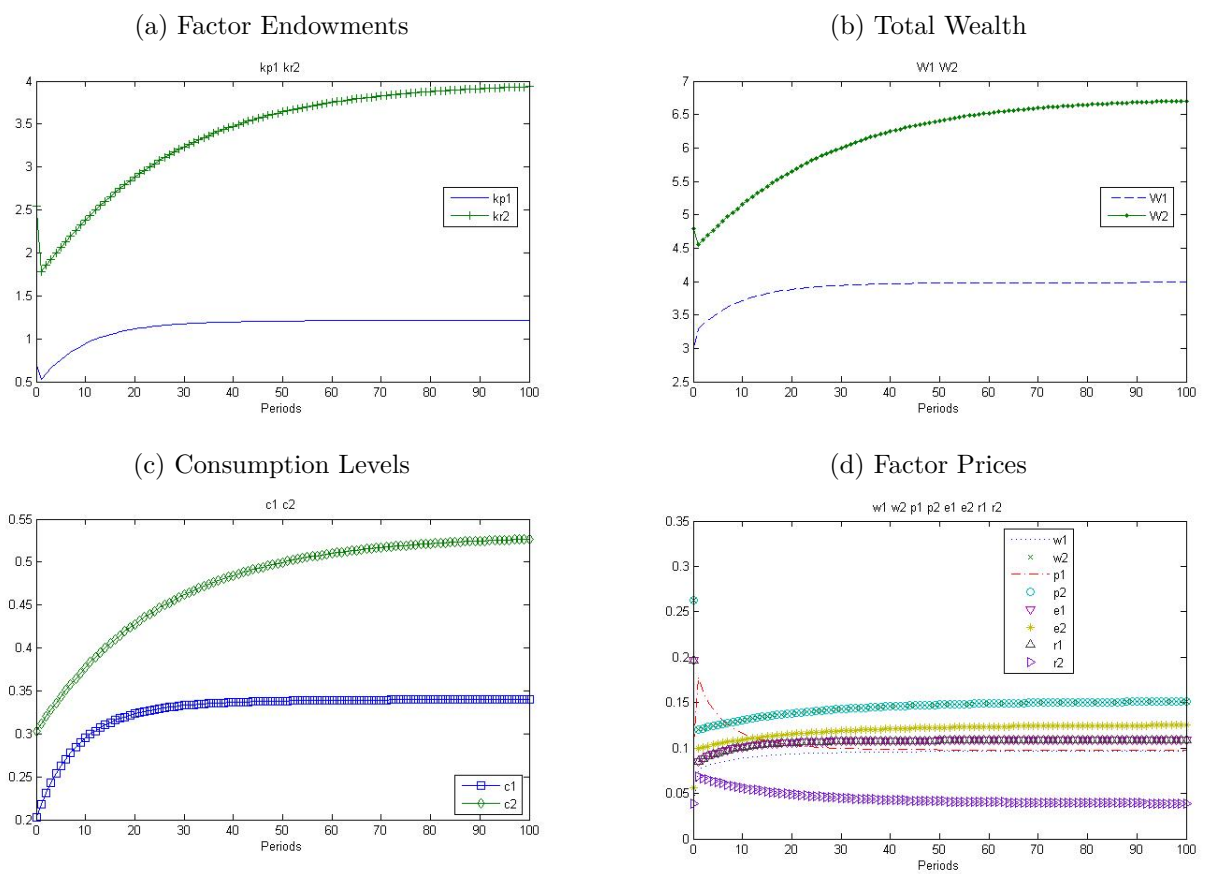
Increasing asymmetry in endowments leads to lower prices for the intermediates constituting the comparative advantage and reallocation of production between the two countries. One has to consider that two factors are used only in one sectors while the two others are used in two sectors. As asymmetry grows, sector 3 must combine a fixed share $(1 - \alpha)$ of increasing endowments which a shrinking share of the two others. This combination inevitably leads to stronger price reaction under CS than under autarky, where all endowments enter production the same way.

While trade magnifies the effect of the shock on prices, it lowers its impact on consumption and investment. The same exogenous increase in asymmetry leads to a lower reduction in world consumption, wealth and endogenous factor endowments. As absolute numbers are higher in country 2, country 1 benefits relatively more from this milder reduction in world consumption, wealth and endogenous endowments. The ability to trade, while demanding stronger price reactions, makes it easier to obtain goods intensive in the shrinking endowment, resulting in lower losses in consumption and investment. The transitional dynamics are presented in figure 3.14.

Transition requires the same adjustment in exogenous endowments as under autarky (32% reduction in the abundant exogenous factor endowment and a 224% increase in the scarce exogenous factors). Under free trade, this shock generates a 70% increase in consumption in country 1 and a 78% increase in country 2. Produced capital in country 1 increases by 74% and renewable resources in country 2 by 58%. Total wealth increases by 37% in country 1 and 43% in country 2. For an equivalent shock, the adjustment is smaller than under autarky even if the resulting increase in consumption and wealth are also smaller. Reflecting the change in the underlying production structure, e_1 , r_1 , w_2 and p_2 are no more moving together, the first two decreasing by 47% and the two others by 44%.

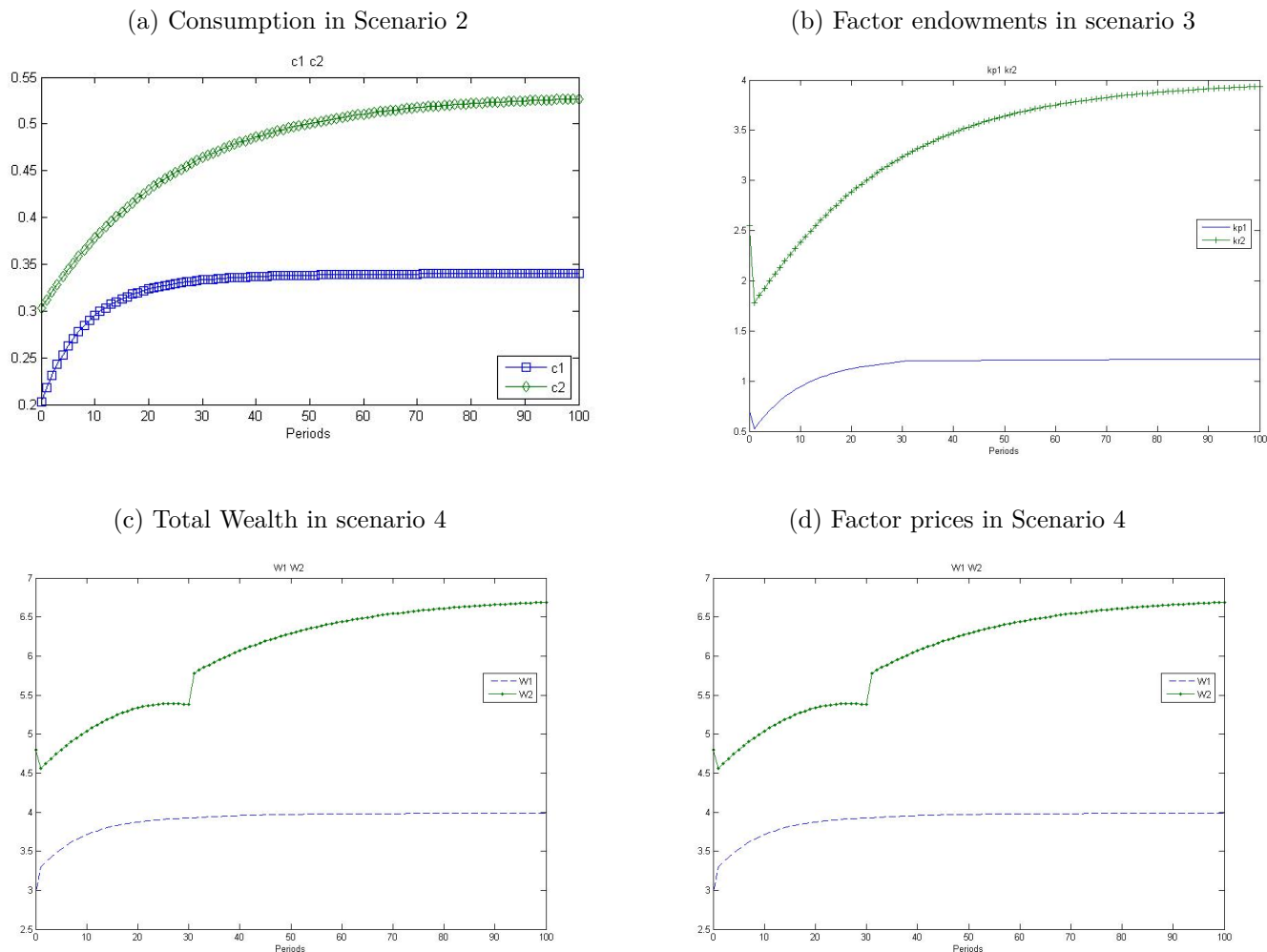
The adjustment is larger than in autarky. p_1 and r_2 are still stable. Interestingly, w_1 and e_2 vary by less than in autarky. This is also a consequence of the new production structure. Reduction in factor abundance has a lower impact compared to autarky while alleviating the constraint from the scarce factor. The shape of the adjustment is virtually unaltered compared

Figure 3.14: Transitional dynamics in CS (permanent shock)



Source: Author's calculation

Figure 3.15: Noteworthy dynamics in CS



Source: Author's calculation

to autarky. Adjustment is still quicker for country 1 and the same sharp decline before a strong bounce-back is observed in the transition path in endogenous capital for both countries.

The figures for all the scenarios are available in appendix E. We only present the most noteworthy in figure 3.15. The obvious change between autarky and free trade is that the partner country is now affected by an shock in the other country. Scenario 1 produces expectable results, with consumption rising by 1.48% in country 1, slightly more than under autarky, but consumption is country 2 now also increases by a small 0.13%. The exogenous boost in labour in country 1 lowers the price w_1 by 4.56%, but also lowers w_2 and p_2 by 0.06% compared to trend, explaining the surge in consumption.

The accumulation of endogenous capital is also amplified by the shock, with Kp_1 and Kr_2 increasing by 2.11% and 0.15% respectively. A positive shock on an exogenous factor

constituting the comparative advantage has a stronger positive effect on the country considered and a milder positive on the partner country. This positive impact is channelled via the reduction in the factor price in both countries. All *relative* prices fall even when some *absolute* prices increase.

Scenario 2 pictures a more interesting setting. As labour supply increases exogenously in country 2, consumption increases although by less than in country 1 in scenario 1. This makes sense as the absolute size of the shock is smaller, since country 2 low asymmetry endowment is smaller. While consumption increases by 0.48% it shrinks by 0.01% in country one. Wealth and produced capital also shrink, while renewable resources in country 2 increase by 0.61%. The transmission of the shock go through relative prices, with three relative prices going up and only one going down. Hence, a positive shock on a capital stock not constituting the comparative advantage has a positive impact on the country experiencing the shock, but a negative impact on the trading partner. As we noted before, this can be explained by the implied reduction in interdependency. Country 2 now needs country 1 less, but country 1 still needs country 2 the way it did before the shock.

This interpretation is confirmed by scenario 3, where the situation is reversed and the shock (relatively) larger. Consumption increase in country 1 by 1.22% while it shrinks in country 2 by 0.04%. Wealth increase in country 1 by 1.98% and produced capital by 1.80%, while in country 2 wealth shrinks by 0.03% and renewable resources by 0.06%. Note that relative prices vary in a symmetric manner, with three relative prices decreasing and one increasing.

Finally, scenario 4 presents the shrinkage of an endowment constituting the comparative advantage in the considered country. The result is unambiguously negative, as it makes the resource constraint on that stock more stringent for everyone. The effect is, as could be expected, more important in country 2 with consumption down by 5.43% when in country one it is only down by 1.11%. As renewable resources are also dis-invested because of the shrinking pool of overall resources, renewable resources are reduced by 6.96% and wealth by 10.44% in country 2. The fall is only 1.66% in produced capital and 0.49% of wealth for country 1. The ambiguity is also lifted from relative factor prices. All absolute prices being reduced e_2 excepted, all relative prices are down.

Those are the results of the simulations of the CA case, under autarky and free trade. We presented the main feature of the autarky model with the interesting consequences of our choice of production structure. The most interesting result of the CA case is the downward relationship between asymmetry in exogenous endowments and our variables of interest. Constrained steady-states characterised by high asymmetry are dominated by steady-states under low asymmetry. It should however be noted that the consumption gap between country 1 and

2 narrows with asymmetry, as do the endogenous endowments and wealth gaps.

The nature of capital accumulation puts country 1 at a disadvantage, as more needs to be invested there to accumulate produced capital. As a consequence, country 2 is better-off across all specifications in autarky. Because of the large gap in wealth implied by this difference, FPE never occurs when both country open-up to trade. The CS equilibrium resulting from free trade is largely similar to the autarky equilibrium in terms of constrained steady-states and transitional dynamics. It is only natural at this stage to question the rationale for opening-up to trade altogether. Both countries are worse-off when going from autarky to free trade, whatever the level of asymmetry, and the transitional dynamics are similar. The differences in the sensitivity to permanent and temporary shocks are discussed below, together with the production structures.

Nevertheless, the CA case stresses a potent reason for opening-up to trade. Under CS, factor prices are lower than under autarky. Even more, the price of factors constituting the comparative advantage rise by a lesser amount than under autarky in the transitional dynamics while the price of the competing factors decrease by a larger amount. This is a standard result in HO models, and it is interesting to see it carry through without FPE and in a dynamic context. To put it plainly, if two countries know themselves to be in a transition from low to high asymmetry, then it will be less costly, even if less rewarding, to do the transition under free trade than in autarky. International trade allows both countries to access, via the goods traded, a wider pool of resources, especially in factors that were scarce under autarky. International trade acts at least as a tool of cost control by bringing international competition to domestic factors, a familiar result.

A final note should be made in this intermediary conclusion regarding the temporary shocks. Our model is parametrised so that there is “symmetry in asymmetry” in endowments. This extra assumption is relaxed using the temporary shocks that only affect one factor at the time. Results under autarky are quite conventional, with an increase in endowment increasing wealth and consumption. The increase is larger when the factor is abundant and as such a source of comparative advantage.

Under free trade, the impact of all shocks is stronger, both when positive or negative. In addition, shocks now reverberate in the partner country, where it can have a negative impact when reducing the comparative advantage. Scenario 4 is quite telling in that respect: a 20% reduction in the exogenous factor source of comparative advantage reduces world consumption by 3.62% in CS against 3.24% in autarky. But in autarky this impact is -5.55% for country 2 and 0 for country 1, when in CS it becomes -5.43% for country 2 and -1.11% for country 1. Trade generates interdependence so that impacts are both more important and spread between

the two countries.

Those first results are obtained when factor price equalisation is impossible and both countries accumulate a different endogenous factor. This situation can be associated to a trade liberalisation between countries that are structurally dissimilar. We can compare those results with the structural change (SC) case where countries aim for a similar economic structure by accumulating the same endogenous factor.

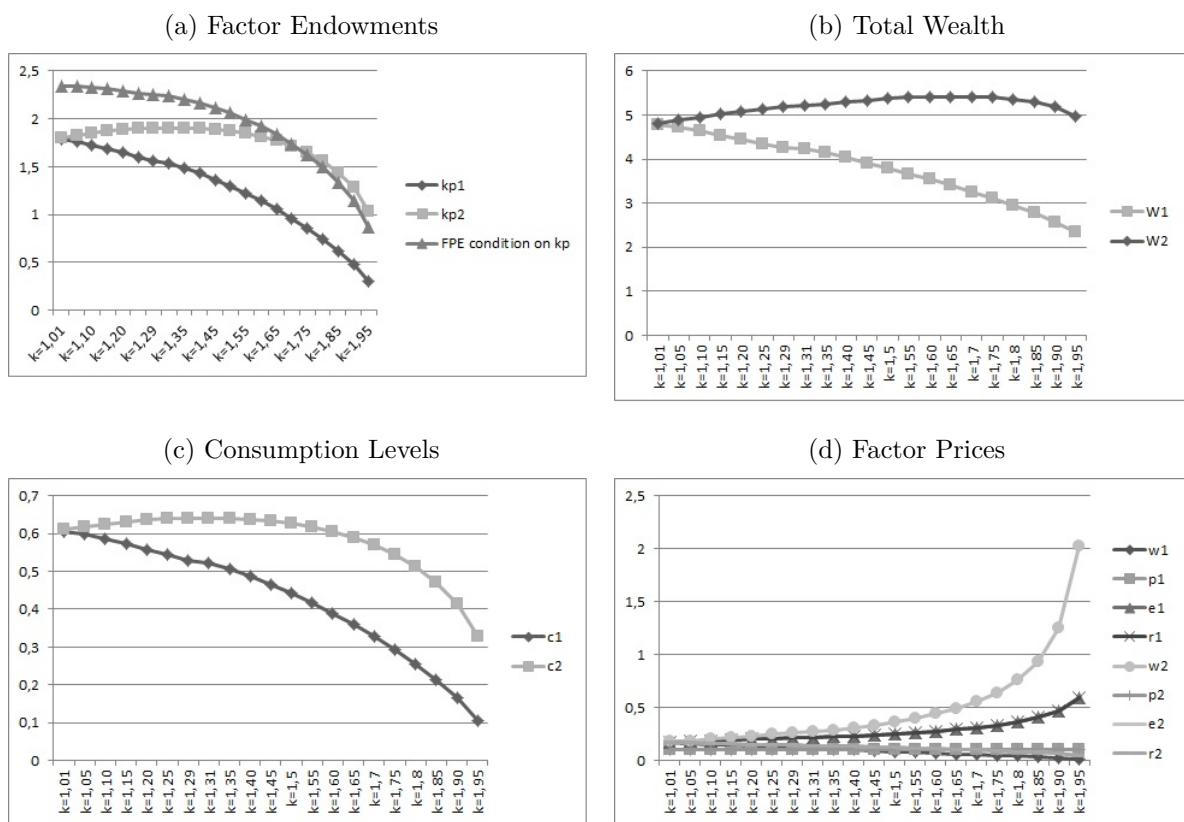
III.4.2 Simulations under the structural change (SC) case

The structural change (SC) case describes consumption and wealth convergence when both countries are accumulating produced capital. The distribution of autarky constrained steady-states SC are available from figure 3.16. As opposed to the CA case, the consumption gap is widening with asymmetry until our high asymmetry equilibrium ($k = 1.75$). While country 1 consumption is constantly decreasing, country 2 consumption increases up to $k = 1.31$ and then starts to decrease. Consumption in country 1 represents 88% of country 2 consumption at $k = 1.19$, decreasing to 54% at $k = 1.75$. Wealth is increasing with asymmetry in country 2, rising by 6.36%, while it shrinks in country one by 30%. Country 1 accumulates less produced capital than country 2, for any asymmetry in exogenous endowments.

The factor prices pattern is interesting. r_1 and e_1 are still moving together and increasing with asymmetry, but the greatest surge is now for w_2 which decorrelates from p_2 . Even under autarky, both countries have the same constant price for produced capital (0.09774). The perfect price correlation in country 2 is now between r_2 and e_2 , mirroring country 1. It should be noted that both countries fulfil the FPE condition for the full range where it is possible in exogenous endowments. The spread $\frac{w_2}{p_2}$ goes from 1.46 to 7 when the spread $\frac{w_1}{p_1}$ goes from 1.39 to 0.49 with asymmetry.

We proceed to the assessment of the transitional dynamics under a permanent shock, moving from high to low asymmetry in exogenous endowments. Results are presented in figure 3.17. It should first be noted that convergence is faster in SC than in CA. Convergence takes 81 periods against 262 in CA. The shape of the convergence path is regular for consumption in both countries, but implies an overshoot downward for produced capital and wealth. Similar overshooting is observed for factor prices, with the exception of p_1 and p_2 . Going along the transitional dynamics yields a 90% consumption increase, a 92% increase in produced capital and 43% increase in wealth for country 1. In the meantime, country 2 witnesses a 17% increase in consumption, a 14.5% increase in produced capital and a 6% reduction in wealth. Overall,

Figure 3.16: Constrained steady-state values under SC in autarky



Source: Author's calculation

the world sees a 42% increase in consumption, 12% increase in wealth and 41% increase in produced capital. Prices move strongly with a 40% decrease for e_1 and r_1 and a 68% increase for e_2 and r_2 . w_1 increases by 183% and w_2 decreases by 64%.

Those figures beg for a comment on the dynamics in SC. Both countries still have an interest to reduce asymmetry in endowments as this means higher consumption. For country 1, this has straightforward implications. As country 1 accumulates the source of its comparative advantage, it can compensate the shrinkage in labour with an increase in produced capital¹⁸. This shift can be done while the constraint of scarce factors is alleviated as the stock of exhaustible resources increases.

Country 2 faces a different challenge. It already faces an increase in labour so that its ability to invest in produced capital yields less gains. At the same time, its advantage in exhaustible resources shrinks. The overall result is reduction in wealth, less gains from the substitution of produced capital for exhaustible resources and a relatively lower increase in consumption. Country 2 faces the challenge of substitutability between opposite sources of comparative advantage¹⁹ when country 1 does not. The world as a whole is still better-off, but country 2 faces a price structure leading to lower reinvestment and reduced wealth.

As with the CA case, we only present the notable elements in the scenarios, in SC (figure 3.18). All the figures are available in appendix E. In all scenarios, idiosyncratic shocks have no impact on the other country. A notable feature of the transition from low to high asymmetry implied by scenario 1 is the overshoot of produced capital in country 1, much larger than in country 2. As a result, produced capital in country 1 is higher than in country 2 for a couple of periods. Scenario 2 produces results quite similar to those under CA. The shock is lower in magnitude than in scenario 1, although still positive via a decrease in the price w_2 .

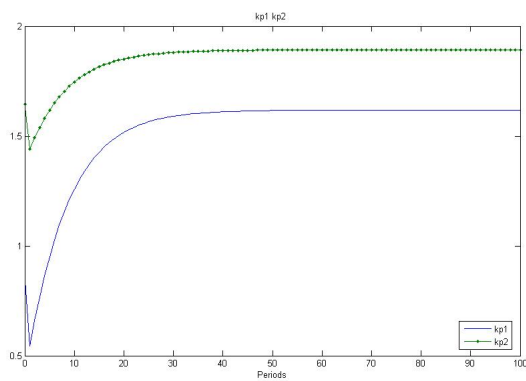
Coupling this observation with the results of scenario 3, we can conclude that positive shocks have less impact on the scarce factor than on the abundant factor in autarky. The 10% increase in labour raised wealth in country 1 by 4.53% when the 20% increase in exhaustible resources raised it by 2.14%. Finally, scenario 4 produces as always the most interesting results. The strong adverse shock on the exhaustible resources creates a 7.10% decline in consumption and 11.8% decline in wealth. Price e_2 surges by 30% while all the other prices fall. After the initial peak from the permanent shock, the path is bell-shaped for consumption, wealth and produced capital. Those three variables start to decline with accelerating speed as the cumulative shock gets strong enough.

18. Remember that between the high asymmetry and the low asymmetry equilibrium, the abundant exogenous factors are reduced by 32%

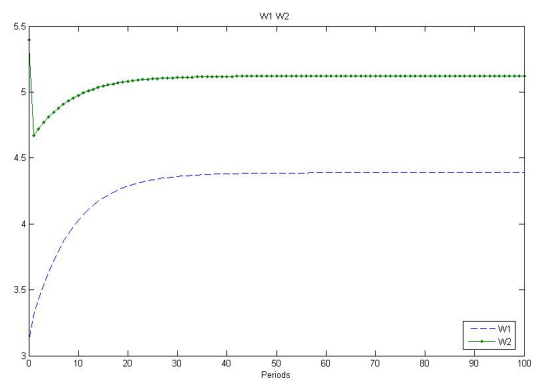
19. If and when the country opens-up to free trade.

Figure 3.17: Transitional dynamics under SC (permanent shock)

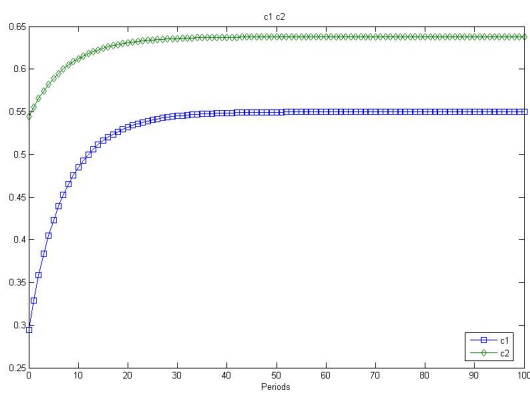
(a) Factor Endowments



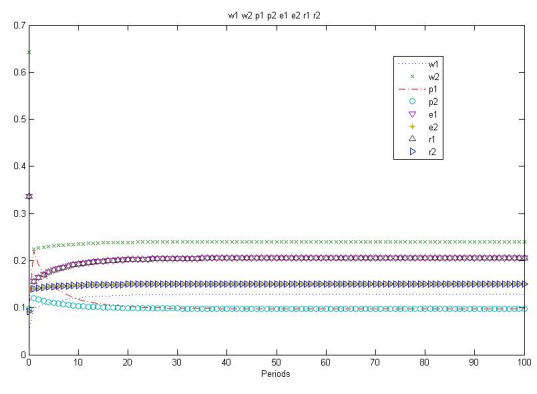
(b) Total Wealth



(c) Consumption Levels



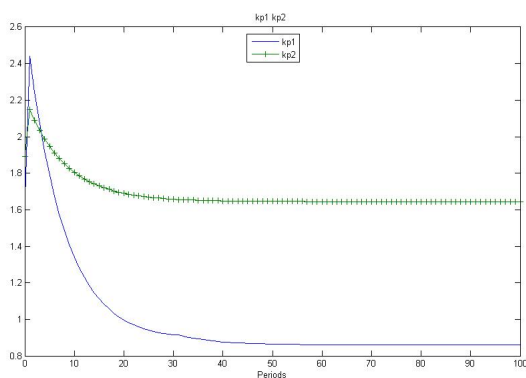
(d) Factor Prices



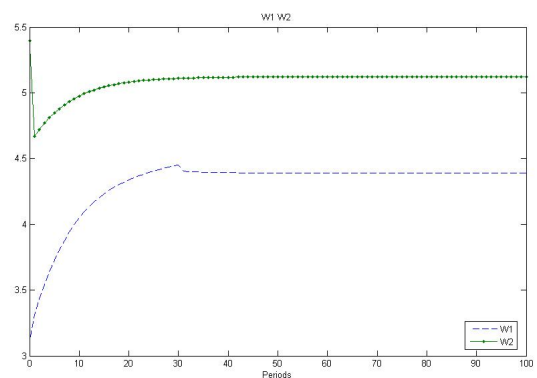
Source: Author's calculation

Figure 3.18: Scenarios in autarky (temporary shocks)

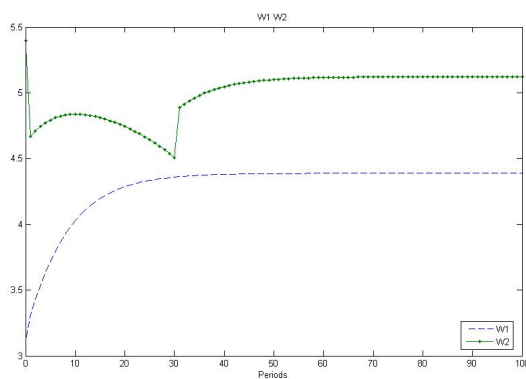
(a) Produced capital, scenario 1



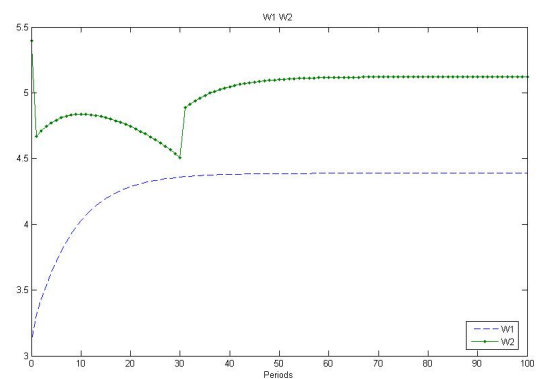
(b) Total Wealth, scenario 3



(c) Total Wealth, scenario 4



(d) Consumption, scenario 4



Source: Author's calculation

The SC case yields constrained steady state values for produced capital that are compatible with FPE under the CS model, so that it is the distribution of exogenous endowments that prevents FPE. Therefore, the CS case should cover the range $k = 1.31$ to $k = 1.75$. Values for k below 1.3 should yield FPE. But under the IE model, FPE breaks down because of the increase in produced capital in country 1 when $k > 1.19$ under a single world-level system of relative prices. We therefore extend the CS model to $k = 1.19$ even if the FPE condition is theoretically verified. For k values in the range $]1.19; 1.31[$ we would need a transitory price system where some factors have a unique world price and some do not. The spread between factor prices in both countries should decrease, as prices converge from CS values to the IE global price system.

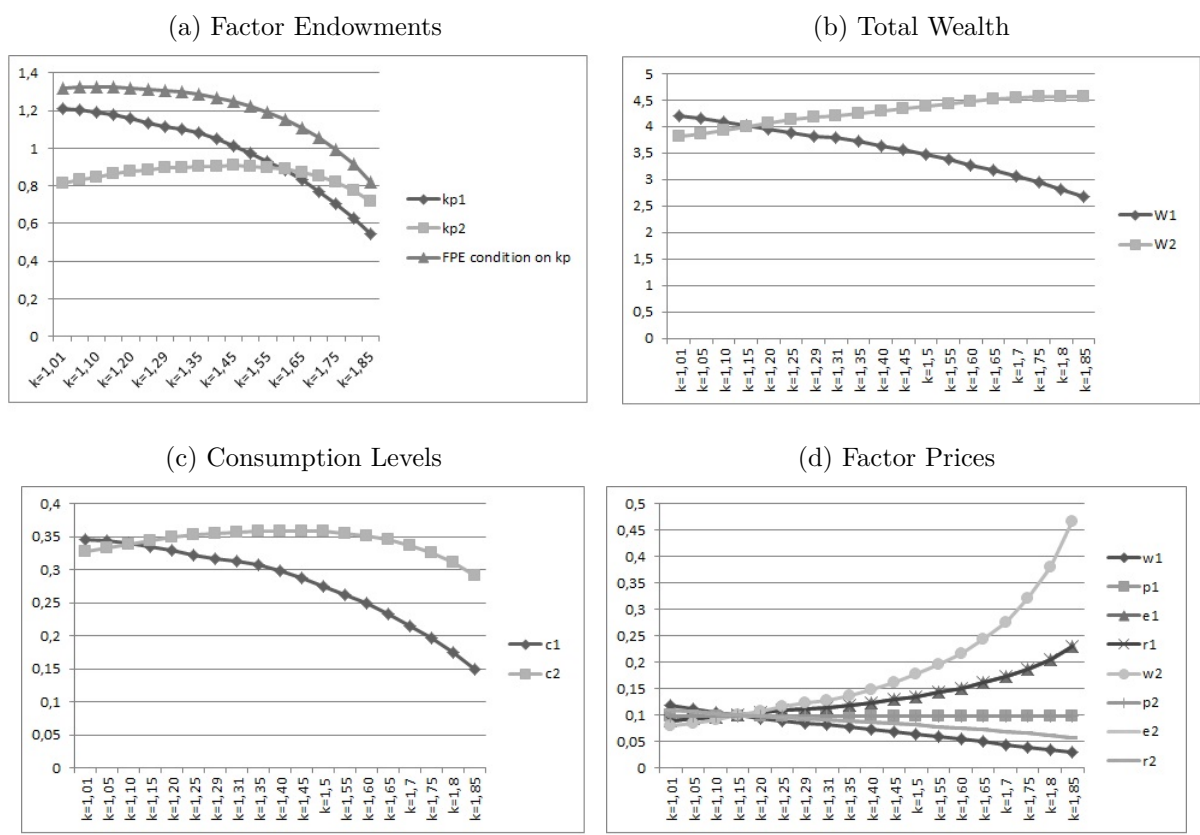
As in the CA case, the CS model in SC yields lower factor prices for any asymmetry than the autarky model. Consumption, produced capital and wealth are all lower than in autarky. The constrained steady state values are displayed in figure 3.19. The transitional dynamics are presented in figure 3.20. The CS transition is similar to the autarky transition, but its features are more contrasted. Consumption in country 1 increase by 68% against 90% in autarky, while in country 2 those numbers are 6% and 16% respectively. Interestingly, this means that consumption in country 1 is 95% of country 2 consumption in low asymmetry. This suggests that the CS price system in low asymmetry is quite close to the IE price system as we almost observe convergence in consumption levels.

Similar figures are observed for produced capital with country 1 increasing its stock by 62.06% against 88.21% in autarky and country 2 7.84% against 15%. Finally wealth in country 1 increase by 32.41% against 41.11% in country 1 and decrease by 9.9% against 5.06% in country 2. It should also be noted that for the first time, country 1 ends up with more produced capital than country 2 in the low asymmetry setting, even with lower consumption and wealth.

As in autarky, consumption in both countries is the only variable of interest not overshooting during the adjustment. Produced capital in both countries overshoot downwards before going up to the new steady-state (much more significantly in country 1) and so does wealth. As under autarky, the price dynamics are interesting. w_1 increases by less and e_1 and r_1 decrease by more than under autarky, while w_2 decreases by slightly more and e_2 and r_2 increase by less. While yielding less impressive results in terms of consumption, produced capital and wealth, free trade proves to be an effective cost control mechanism, especially for wages in country 1. The adjustment there is obtained via overshooting in period 1.

Diagrams for the scenarios are presented in figure 3.21. Scenario 1 follows an expected pattern, with a positive shock on labour in country 1 rising consumption, produced capital use and wealth in both countries, although much more significantly in country 1. It should be noted that the increase is slightly higher in country 1 compared to autarky, as the fall in w_1

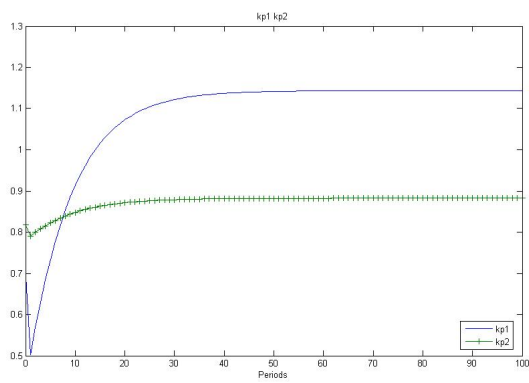
Figure 3.19: Constrained steady-state values in CS



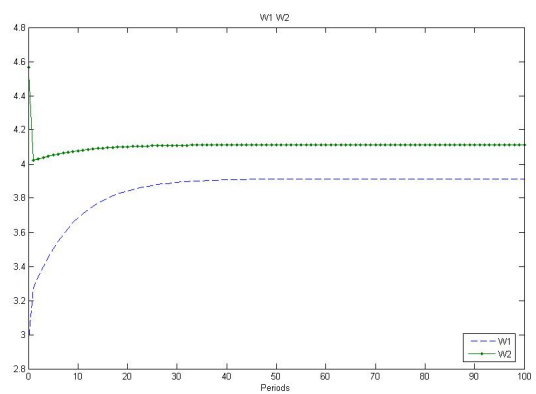
Source: Author's calculation

Figure 3.20: Transitional dynamics in CS (permanent shock)

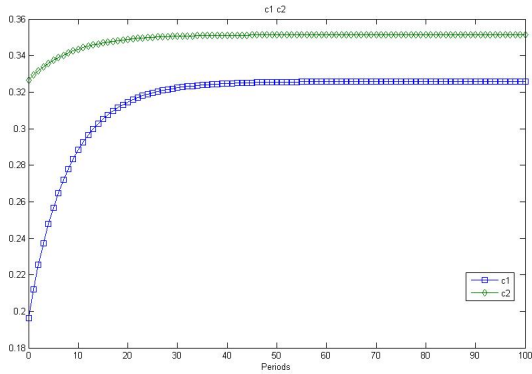
(a) Factor Endowments



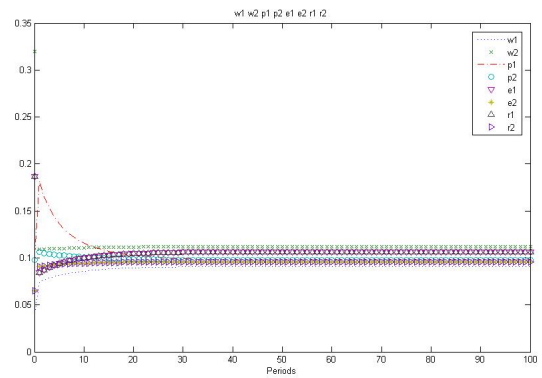
(b) Total Wealth



(c) Consumption Levels

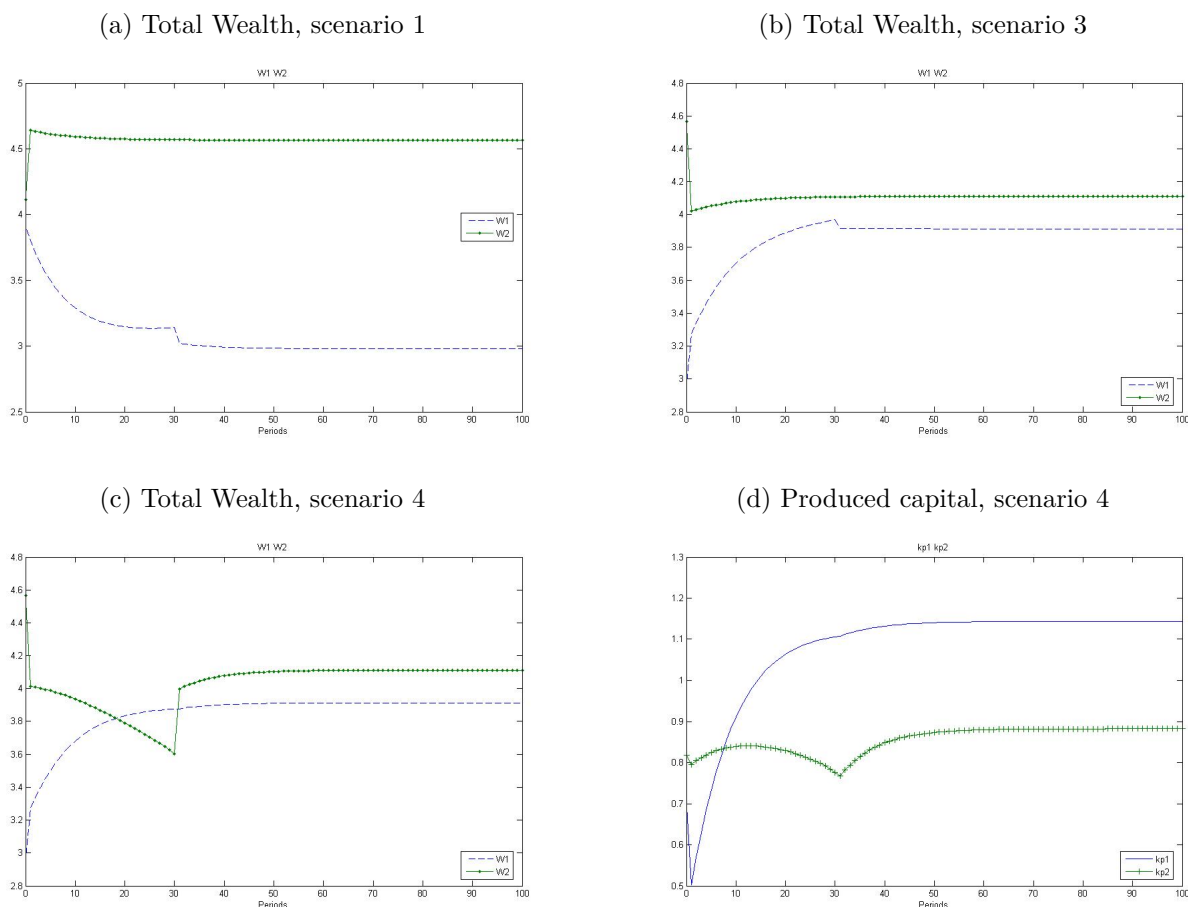


(d) Factor Prices



Source: Author's calculation

Figure 3.21: Scenarios in CS (temporary shocks)



Source: Author's calculation

is slightly larger and the increase in p_1 somewhat lower. Country 2 on the other hand sees a decrease in w_2 and p_2 . This decrease is larger than the fall observed in country 1. Still, the world consumption, produced capital and wealth increase is larger than in autarky.

In scenario 2, the positive shock on labour in country 2 has mild adverse consequences for country 1. As consumption increase by 0.66% in country 2 it falls by 0.03% in country 1. A similar story is observed with wealth, increasing by 0.88% in country 2 and falling by 0.007% in country one. This is the result of relative factor prices going in opposite direction, with two factor price ratios going up and two going down, when in scenario 1 they were all moving in the same direction. Scenario 3 as always mirrors scenario 2, with consumption, produced capital and wealth decreasing in country 2 while they increase in country 1. As the shock is larger, the negative impact is more important than in scenario 2.

Compared to autarky, the model replicates its cost control dimension with price w_1 and r_1 rising by less than under autarky and e_1 falling by more. Only p_1 increases because of higher

produced capital accumulation. This is more than compensated by the general fall in factor prices in country 2. Scenario 4 once again yields the largest response to the largest shock. As all factor price ratios fall, consumption is reduced by 0.8% in country 1 and 7.15% in country 2. Wealth and produced capital are reduced by respectively 12.28% and 11.68% in country 2 and 0.42% and 1.46% in country 1. Interestingly, the cost control properties of trade are playing against country 2 in this negative shock, as the milder price response generates a stronger reduction in consumption, produced capital and wealth than under autarky. The world is as a result worse-off than under autarky, with all variable of interest at the world level reduced in CS compared to autarky.

We now turn to the IE equilibrium. The IE equilibrium tolerates a maximum asymmetry in endowments of 68% which is already quite large (see below). But it only represents 5 constrained steady-states, so that we present the results in synthetic table 3.5. As we saw above, under SC opening-up to trade results in the integrated equilibrium for $k \leq 1.19$. Under SC, it is possible to go from autarky to the IE trade model if countries open-up to trade with low enough asymmetry as the FPE condition is respected in all factors for $k \leq 1.30$. Both countries should also move to the IE equilibrium from the CS equilibrium for a similar value. But as we saw, in the IE setting, FPE occurs only starting with $k = 1.19$.

We therefore start our study of the IE equilibrium in SC by presenting the transitional dynamics from the autarky and SC constrained steady-states values to the IE constrained steady-states values for $k = 1.19$. As factor prices are equal in IE but not in CS or autarky, we take the constraint steady-state values for $k = 1.19$ in the CS model and impose an exogenous shock of factor price equalisation on those values²⁰. We then use those shocked values as the initial values for the transitional dynamics in the IE model, to obtain a transition path from CS to IE. Results are presented in figures 3.22 and 3.23.

As we saw above, consumption, produced capital and wealth are high in autarky for the low asymmetry steady-states. As a consequence, opening-up to trade when asymmetry is low is likely to result into consumption and wealth losses. The transitional dynamics confirm this intuition, with world consumption reduced by 43%, world wealth by 15% and world produced capital by 42%. At the country level, consumption is reduced by 39.5% in country 1 and 46.5% in country 2. Wealth is reduced by 7.5% in country one and 22.8% in country 2. Finally, produced capital is reduced by 20% in country 1 and a staggering 61.5% in country 2. The adjustment is carried through a 44% fall in w and a 43% fall in e and r . In the IE equilibrium factor prices are not only equalised between countries, but also between exogenous variables so

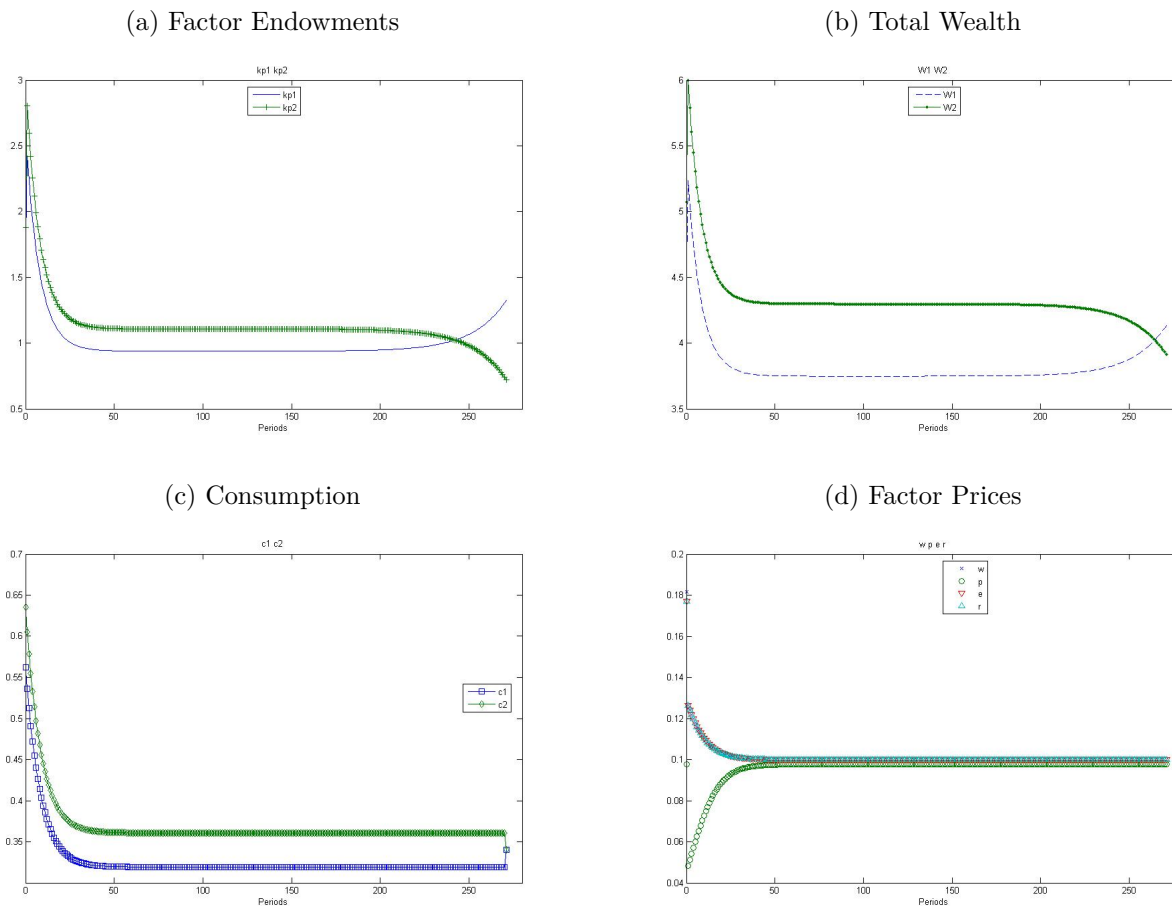
20. As countries are of equal size, we take the average of the steady-states factor prices in both countries as the shock values.

Table 3.5: Transitional dynamics between AU and IE (permanent shock)

regime	IE	IE	IE	IE	IE	IE
hypothesis	SC	SC	SC	SC	SC	SC
size	k=1,01	k=1,05	k=1,10	k=1,15	k=1,19	k=1,2
c	0,680031	0,680031	0,680031	0,680031	0,680031	0,680031
W	8,046406	8,046406	8,046406	8,046406	8,046406	8,046406
Y	0,800071	0,800071	0,800071	0,800071	0,800071	0,800071
kp	2,046406	2,046406	2,046406	2,046406	2,046406	2,046406
kl	2,000000	2,000000	2,000000	2,000000	2,000000	2,000000
ke	2,000000	2,000000	2,000000	2,000000	2,000000	2,000000
kr	2,000000	2,000000	2,000000	2,000000	2,000000	2,000000
c1	0,340015	0,340015	0,340015	0,340015	0,340015	0,340015
c2	0,340015	0,340015	0,340015	0,340015	0,340015	0,340015
W1	4,029022	4,052297	4,081392	4,110487	4,133762	4,139581
W2	4,017384	3,994108	3,965014	3,935919	3,912644	3,906825
Y1	0,400582	0,402766	0,405496	0,408227	0,410411	0,410957
Y2	0,399490	0,397305	0,394575	0,391845	0,389660	0,389114
kp1	1,039022	1,102297	1,181392	1,260487	1,323762	1,339581
w1	0,100009	0,100009	0,100009	0,100009	0,100009	0,100009
p1	0,097741	0,097741	0,097741	0,097741	0,097741	0,097741
e1	0,100009	0,100009	0,100009	0,100009	0,100009	0,100009
r1	0,100009	0,100009	0,100009	0,100009	0,100009	0,100009
kp2	1,007384	0,944108	0,865014	0,785919	0,722644	0,706825
w2	0,100009	0,100009	0,100009	0,100009	0,100009	0,100009
p2	0,097741	0,097741	0,097741	0,097741	0,097741	0,097741
e2	0,100009	0,100009	0,100009	0,100009	0,100009	0,100009
r2	0,100009	0,100009	0,100009	0,100009	0,100009	0,100009
sigma	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000
nu	0,977319	0,977319	0,977319	0,977319	0,977319	0,977319
tau	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000
kappa	0,977319	0,977319	0,977319	0,977319	0,977319	0,977319
FPE condition on kp	1,330164	1,330164	1,330164	1,330164	1,330164	1,330164

Source: Author's calculation

Figure 3.22: Transitional dynamics between AU and IE (permanent shock)



Source: Author's calculation

that $w = e = r$ while p is slightly lower.

As for the shape of the transition, there is a large downward shock in period 1 for all variables. While w , e and r slowly converge downward to their steady state level, p converges steadily upward during the first 50 periods. All prices remain stable at the steady-level afterwards. Consumption decreases steadily in both countries before converging to the same level in the last period. Wealth and produced capital move together as in all permanent shocks, decreasing at the beginning of the adjustment before going upwards in country 1 and downwards in country 2 to their steady-state levels. When in autarky country 2 was better endowed than country 1, the opposite happens in the IE equilibrium although both are worse-off in the process.

The transition from the CS equilibrium to the IE equilibrium is a small permanent shock, as values are quite similar. The CS equilibrium for low asymmetry values already yielded close values for steady-state consumption. In IE, we finally observe convergence in consumption as

consumption rises by 2.77% in country 1 and falls by 2.30% in country 2. Produced capital increases 14% in country 1 and decreases 17% in country 2, widening the gap observed in the CS equilibrium.

Wealth increases by 4.15% in country 1 and falls by 3.69% in country 2. Although the adjustment is asymmetric with country 2 losing out, the world as a whole witness an increase of 0.16% in consumption and wealth, and 0.65% in produced capital so that the overall effect of integration is slightly positive. As factor price equalisation was very close under the CS equilibrium, the price response during the transition is very mild, with w increasing by 0.30% and e and r falling by 0.68%. As the world economy gets fully integrated, all exogenous factors have the same price so that $w = e = r$ with p marginally cheaper.

As for the shape of the transition, we kept the same length of 270 periods. Produced capital and wealth start with a small progressive surge in the first periods, before starting to converge to the new steady state in around 70 periods. Consumption also surges to start with, before a sudden adjustment in the last period as the total adjustment is quite small. Prices only move in the first periods, rapidly reaching their steady-state values.

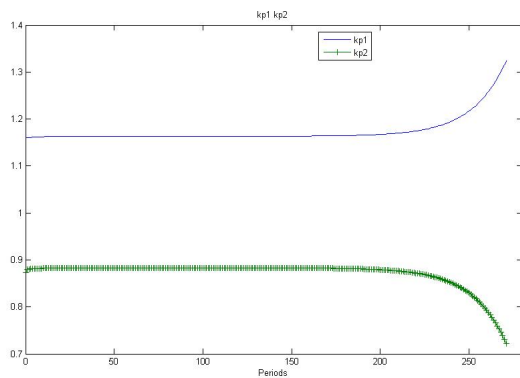
The integrated equilibrium (IE) fits nicely as a consequence of structural change after the CS phase. It seems a far less natural and interesting setting to reach from autarky. As always, we test our scenarios on the IE equilibrium. Notable results are available in figure 3.24. The $k = 1.19$ constrained equilibrium being the upper limit of the IE model in terms of asymmetry, we choose an arbitrary level of asymmetry, $k = 1.1$ as the “low asymmetry” equilibrium.

Comparison of the temporary shocks between IE and CS or autarky should only be tentative, as although the shocks are of the same size, they are implied on transitions of different magnitudes. In the transition in IE, asymmetry is reduced by far less than in CS or autarky. Nevertheless, comparisons of volatility can be made between the percentages of change, as again the shocks are of the same size. A first important difference between IE, CS and autarky is the nature of the adjustment to the shock. In IE, consumption is always equal between country 1 and country 2. What changes under the shocks is the level of produced capital and the composition of wealth. In the context of the scenarios, another concern is FPE. In scenario 1, the shock produces a level of produced capital in country 1 that is above the $k = 1.19$ steady-state level. Still, as produced capital in country 2 also increases by a larger percentage, FPE is preserved. This is however proof than an increase in asymmetry near the FPE limit has the potential to produce reversion to the CS model.

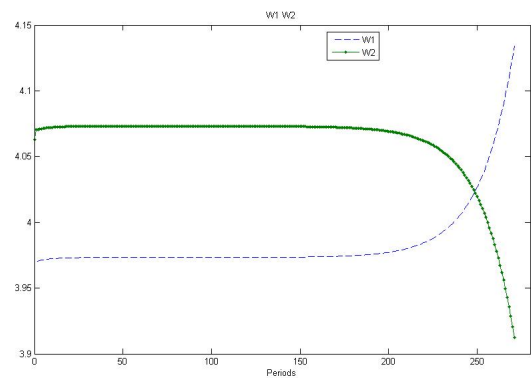
In scenario 1, the positive shock on labour in country 1 results in a 1.33% increase in consumption in both countries. At the same time, wealth increases by 4.53% in country 1 and

Figure 3.23: Transitional dynamics between CS and IE (permanent shock)

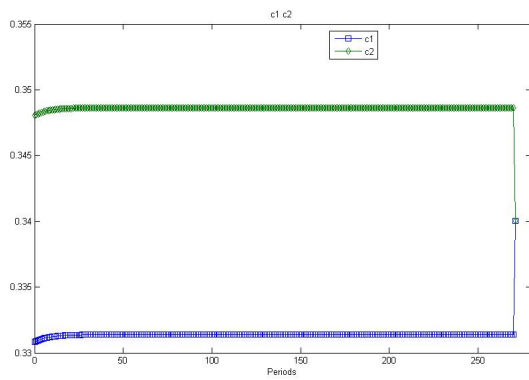
(a) Factor Endowments



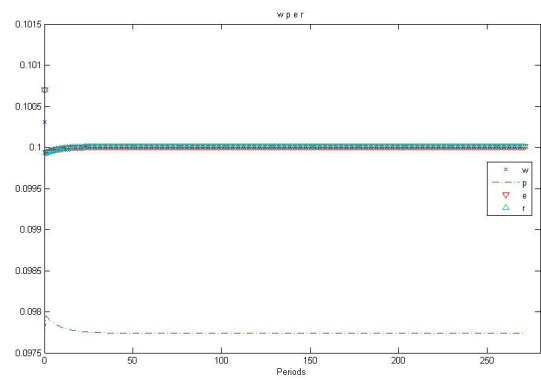
(b) Total Wealth



(c) Consumption



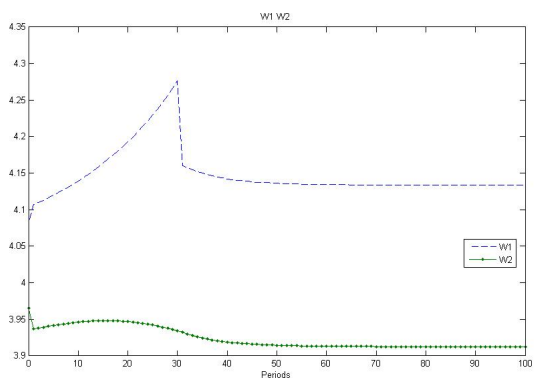
(d) Factor Prices



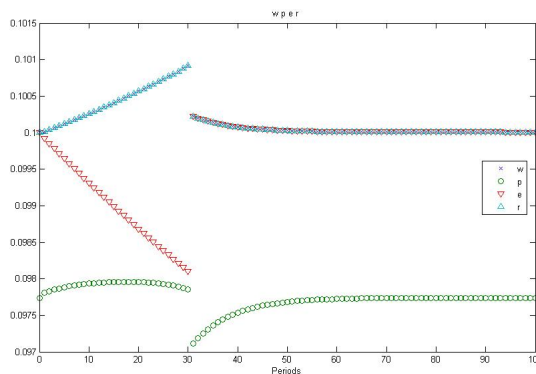
Source: Author's calculation

Figure 3.24: Scenarios in free trade (IE) (temporary shocks)

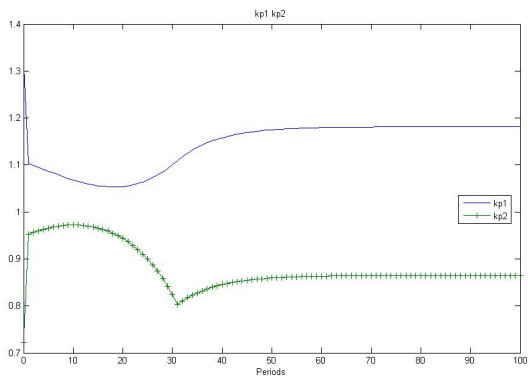
(a) Total Wealth, scenario 1



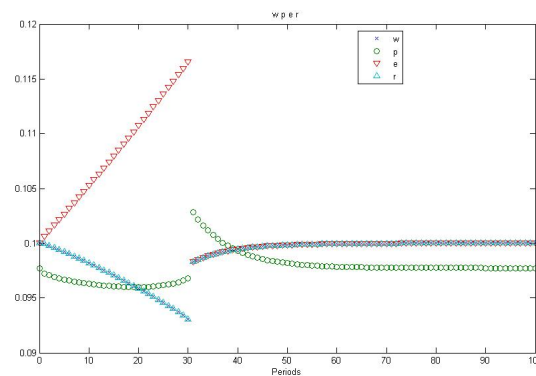
(b) Factor Prices, scenario 3



(c) Factor Endowments, scenario 4



(d) Factor Prices, scenario 4



Source: Author's calculation

produced capital only by 1.49%. The respective percentages in country 2 are +0.54% and +2.96%. As country 1 experiences a positive exogenous shock on one of its endowments constituting its comparative advantage, wealth increases more than proportionally and produced capital less than proportionally. This can be understood as a price-induced internal redistribution between the productive sectors in reaction to factor prices movements²¹. Country 2, facing a lower price for labour, produced capital and experiencing stability in exogenous endowments reacts by increasing more than proportionally its stock of produced capital.

The same effect is observed in all 4 scenarios, for both positive and negative shocks. When under the autarky or CS equilibria the bulk of the adjustment lied with the country experiencing the temporary shock, it lies with the trading partner in IE. The second important feature is the magnitude of the shocks. In scenario 2 and 3, when the factor affected is not constituting the comparative advantage, the magnitude of the shock for all the variables of interest is lower in IE than in autarky or CS. The opposite is true in scenarios 1 and 4.

In scenario 3, world consumption increases by 0.5% in IE, 0.66% in autarky and 0.53% in CS. In scenario 1, world consumption increases by 1.32% in IE, 0.5% in autarky and 0.63% in CS. The general conclusion would be that the IE equilibrium reduces the sensitivity to shocks on the non-comparative advantage factors, but magnifies the shocks on comparative advantages factors. As we will discuss below, this feature is particularly important for scenario 4, as reductions in the exhaustible resources pools in one country have a) a bigger impact in IE than in any other case and b) have a larger impact on produced capital in country 1 than in country 2.

This concludes our presentation of our four scenarios under the two cases (CA and SC) and three different trade settings (autarky, CS and IE). In the next section we discuss those results and propose lessons for sustainability and international trade.

IV Discussion of the results

We discuss the results in three subsections. We first present the sequential nature of the decision to open-up to trade. We then assess the rationale behind this decision compared to autarky. We end the discussion with recommendation for ANS and wealth assessments in open economies.

21. Bear in mind that in IE, the production structure is indeterminate as there are more goods than factors.

IV.1 The decision tree

It is necessary to start this commentary by the assumptions of the model. The first assumption is the most important. We assume, in line with capital theory, that any resource can be considered an instrument of wealth and that all those instruments add to the value and volume of production in any country. It is desirable to have access to all the instruments accounted for on the planet, either directly or through imports of goods and intermediates intensive in those instruments. Instruments can be regrouped into broad categories based on the dynamics of accumulation and de-cumulation of the instrument. The difference between instruments, in our model in particular, is therefore based on the dynamics of accumulation. This assumption does not preclude fungibility and substitutability in money-value, as it is precisely the interest of using capital theory.

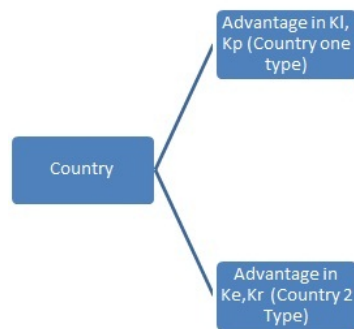
Based on this first assumption, we assume that goods are produced with more or less of a given instrument of wealth. We use in our model the corner case where four intermediates are produced using only one instrument of wealth and one intermediate using all instruments equally. This assumption is consistent with the first one in the sense that as countries desire accessing the largest possible range of instruments of wealth under any form, they will be willing to trade for instruments or instruments embodied in goods, as a way to be better-off. Therefore, differences in factor endowments between countries produce a rationale for trade. A necessary corollary of this assumption is that the more asymmetric the distribution of endowments between countries, the more trade is likely to take place.

The third assumption is about technology and the production structure we derive from it. As we assume that both countries produce one final good from intermediates, we assume also that a) the production process can be divided in substitutable (under constraint) and autonomous entities and b) that domestic resources need to be ventilated between the production requirements of those intermediates. As we introduce a total factor productivity term Φ in the production function, with $0 < \Phi < 1$ we also assume decreasing returns to scale, that is coordination and energy²² costs associated with production. In this perspective, it makes sense that dividing further the supply chain for the final good by adding intermediates can only impact negatively overall productivity.

We believe those assumptions constitute a sound basis to assess the options faced by countries engaging in sustainable development. The conclusions of our model on the issues of sustainability and structural change in the context of international trade are in our view best presented as a decision tree. Let us first consider a country endowed with a set of instruments

22. Or entropy.

Figure 3.25: Decision tree 1



Source: Author

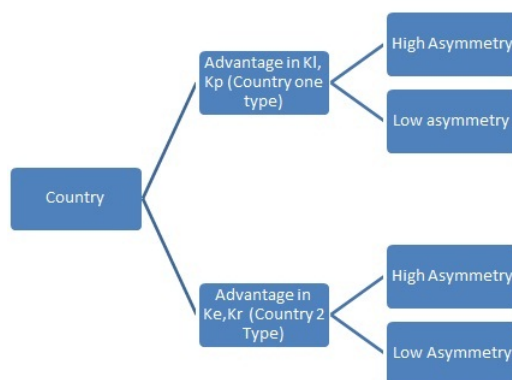
of wealth²³. In line with our assumptions, the first important difference is going to arise from the distribution of instruments in the country. Under a given production structure, those instruments can be separated in terms of relative intensity with respect to the endowments in the rest of the world. This gives the basic definition of potential comparative advantages in figure 3.25, applied to our model.

The second element that matters under our production structure is the extend of the asymmetry. This can be represented by the two constrained steady-states we identified as the low asymmetry and high asymmetry constrained steady-states (see figure 3.26). As was made clear in our study of the transitional dynamics, this is critical to identify the potential gains from reducing asymmetry.

The next step requires the identification of the instruments of wealth forming the basis of development. What is critical is to assess whether the country is going to focus on the accumulation of instruments it is relatively well-endowed with (with respect to the rest of the world) or not. In our model this is the CA hypothesis against the SC hypothesis. In the model we abstract from the case were several instruments are endogenously accumulated

²³. Or capital stocks in the wealth accounting vobable, and factor endowments in the standard economics jargon.

Figure 3.26: Decision tree 2



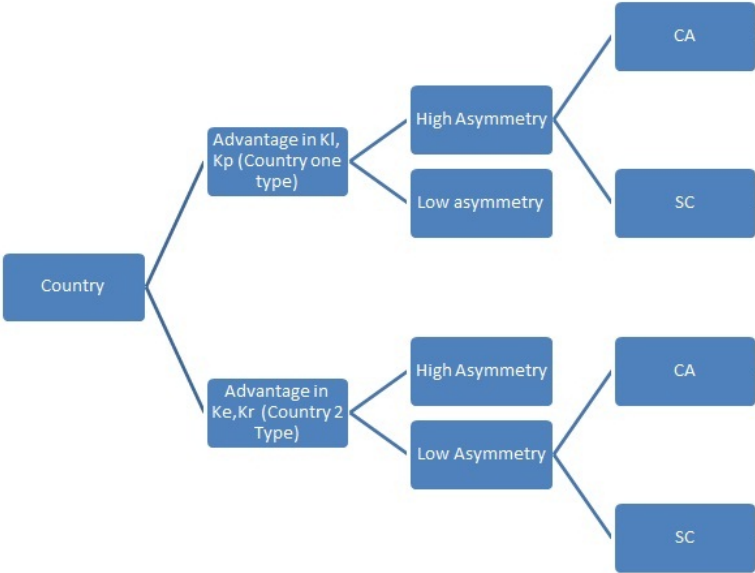
Source: Author

together for the sake of clarity, but also because of the fact that some instruments of wealth dynamics are affected by extra economic factors and can therefore be considered as exogenous. Also, development theory stresses substitution in instrument and the push to accumulate more produced capital as the most common and salient manifestation of development. We consider the CA hypothesis as relevant to examine what would happen if two countries were not focusing on the same instrument of wealth and the SC case as the common case were all countries try to build-up a produced-capital intensive economy. This gives the next set of choices in figure 3.27.

Our model allows for a comparison between SC and CA under autarky and trade. In autarky, there is obviously no difference for country 1. An expected result is that world produced capital is higher in the SC case. A more interesting observation is the fact that the CA case yields higher values for consumption, wealth and renewable resources for the world and country 2 when asymmetry is low, but this advantage narrows as asymmetry increases. Starting at different levels of asymmetry from $k = 1.60$ the difference becomes gradually positive. Therefore, the CA strategy is dominated when asymmetry in endowments is high, and the SC strategy is dominated when asymmetry is low.

This feature comes, as always, from the differences in endowments and its consequences

Figure 3.27: Decision tree 3



Source: Author

on factor prices. Under the CA hypothesis, the price p_2 increases with asymmetry since the endowment is shrinking in country 2. Under SC, country 2 invests in K_p , preventing the rise while price r_2 is kept stable by the parallel increase of K_e and K_r . We can therefore claim that the CA strategy, investing in an endowment that does constitute the comparative advantage, is a dominant strategy when asymmetry is low, that is when the scarce factors are not too scarce. Conversely, if some factors are becoming scarcer, it makes sense to invest in them instead so as to alleviate the consequences of scarcity on production, consumption and wealth.

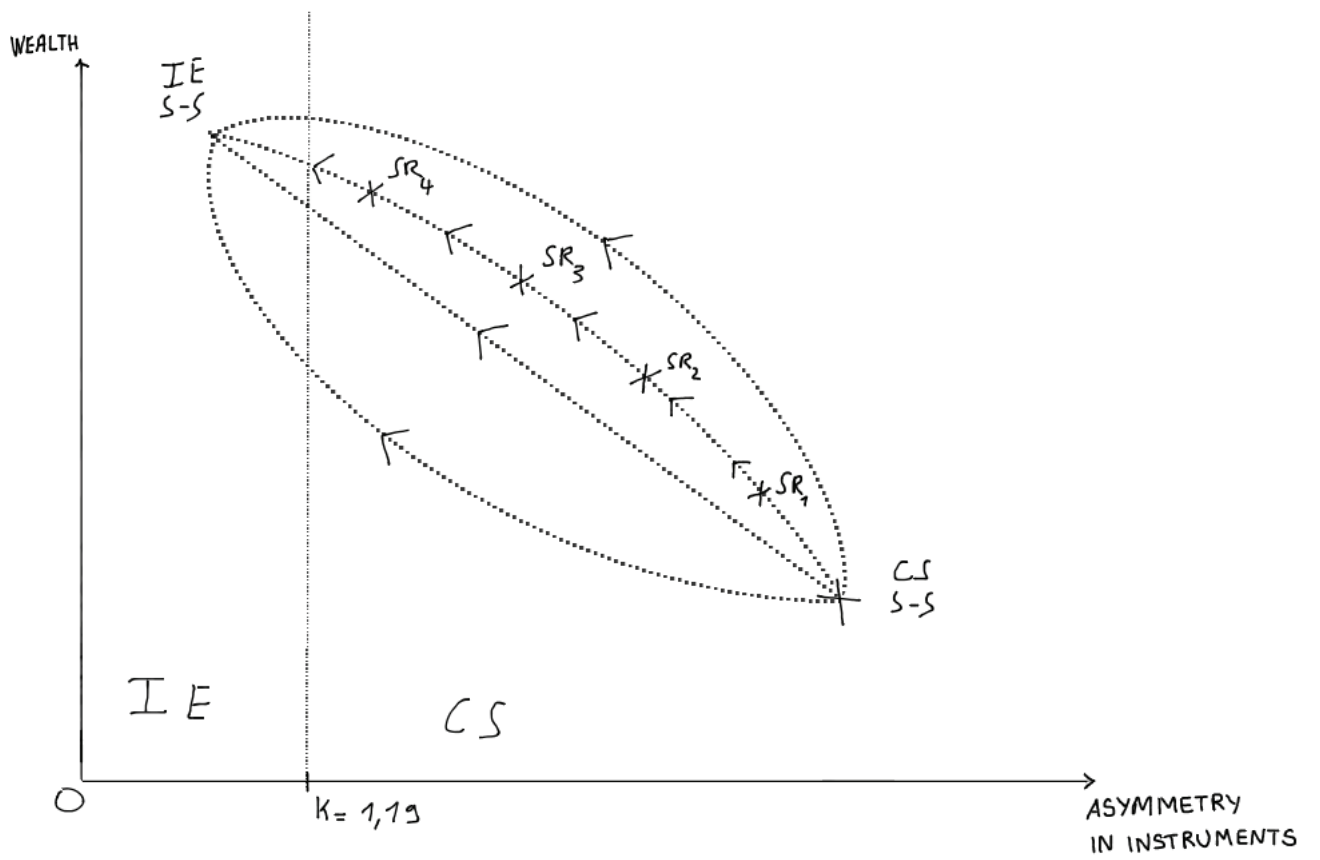
In the next step it is important to consider the consequences of the decision to take three instruments out of four as exogenous variables. This decision produced a series of steady-states with an endogenous level of produced capital or renewable resources, constrained by the three other exogenous instruments. Those constrained steady-states are an approximation, controlling for asymmetry in instruments, of what would be a unique steady-state²⁴ if all instruments were endogenously determined. Together, they define a path between two steady-states which correspond to theoretical starting and ending points. The low asymmetry constrained steady-state is also a switching point to the integrated equilibrium under SC. To define this path, we assumed a symmetric increase in asymmetry (asymmetric increase in asymmetry being presented in the scenarios). Still, as illustrated in figure 3.28 other paths are possible depending on the values of exogenous instruments.

The notion of structural change is indeed at the core of development, usually considered to be both the signal and the cause of it. Our results show that high asymmetry in endowments produces lower levels of consumption, wealth and produced capital. We can therefore consider the push for structural change as a rational desire to increase consumption and wealth, the mean to this end being reduced asymmetry. Our model does not provide an endogenous mechanism for the transition from one constraint steady-state to another, but the elements of political economy, environmental economics and innovation presented in chapter 1 and 2 provide many rationales for this. As explained in the presentation of the results, for country 2 types the reduction in asymmetry is mostly about a sound application of the Hartwick rule. For country 1 countries, the background story is the industrial revolution with its large labour/produced capital substitution, with the joint unveiling of new natural resources such as coal, oil and a boost in agricultural production. Hence, although the reasons for structural change are of prime importance, they can here only be postulated in our model. We focus on the “how” rather than the “why”.

Travelling from high asymmetry to low asymmetry can be undertaken either in autarky or in

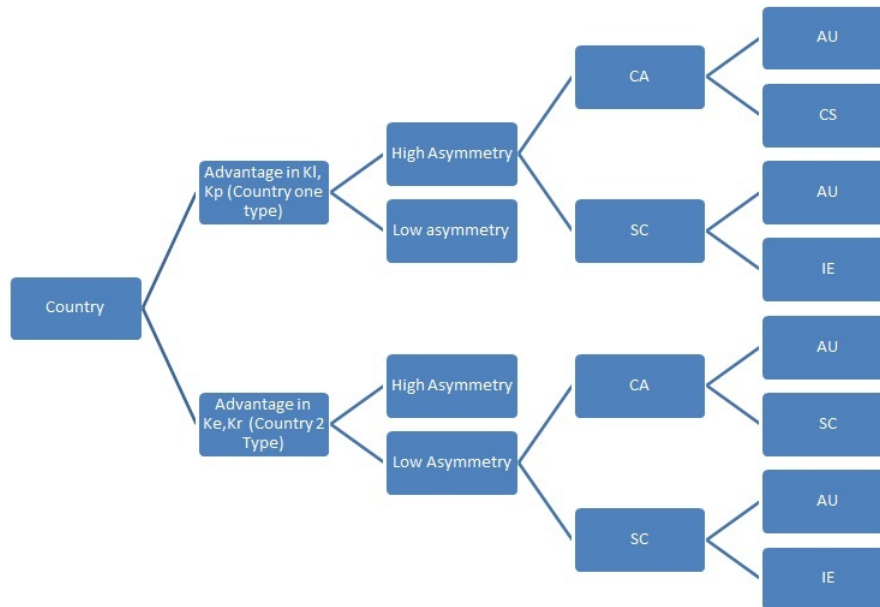
24. Or more accurately two steady-states: one under factor price equalisation, another when factor price equalisation breaks down.

Figure 3.28: Constrained Steady-States as a function of asymmetry in free trade



Source: Author's calculation

Figure 3.29: Constrained Steady-States as a function of asymmetry in free trade



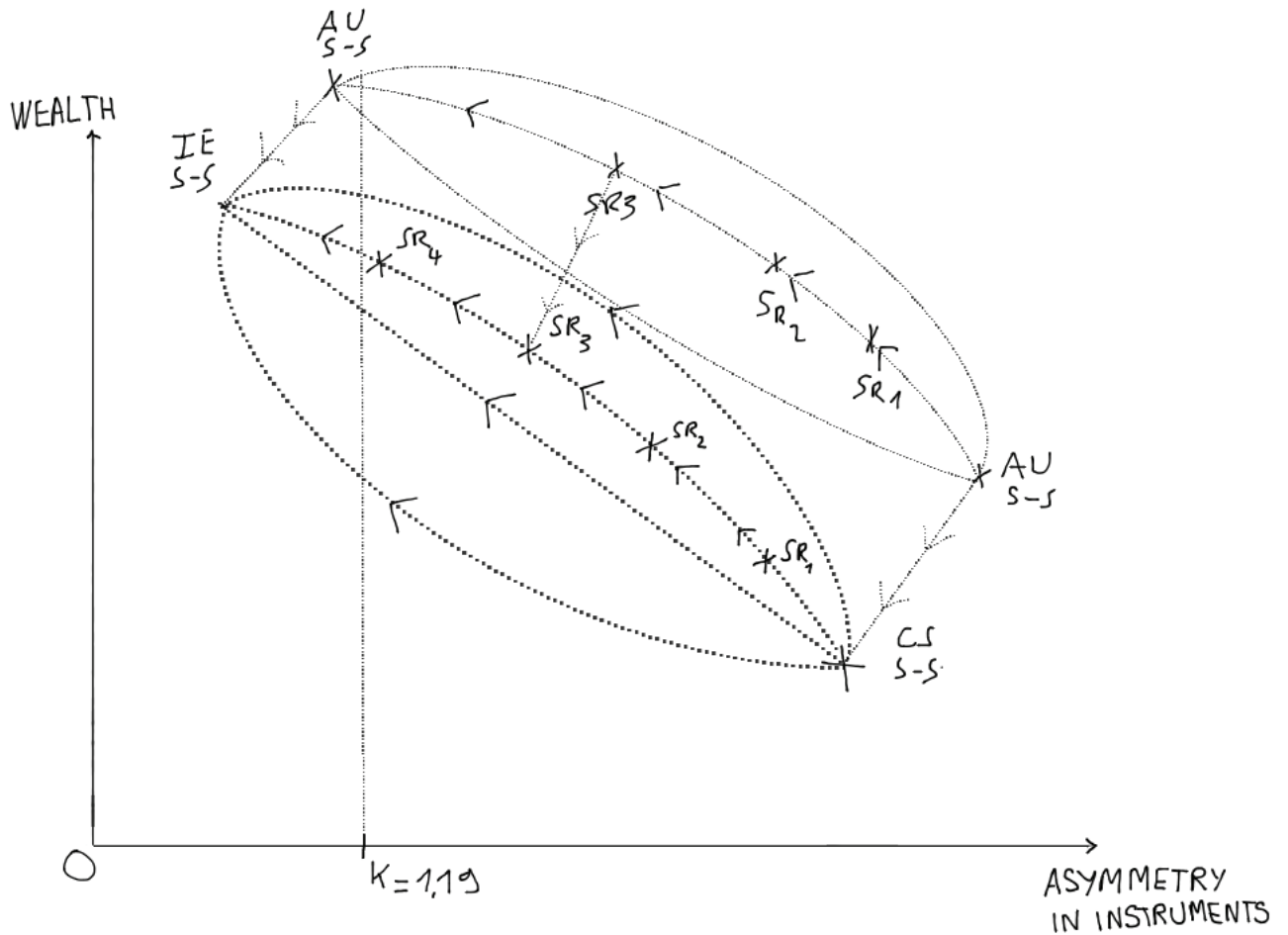
Source: Author

free trade. Choosing free trade under the SC hypothesis will ultimately yield the IE equilibrium, when in the other cases it systematically yields CS. The final decision tree in 3.29 represents this trade-off. Here our model produces an interesting insight. Autarky equilibria under any hypothesis systematically yields higher values for wealth consumption and endogenous factor endowments in both countries for a given hypothesis (CA or SC).

As presented in figure 3.30 opening-up to trade in our model systematically leads to lower values for the variables of interest, so that going from autarky to free trade is equivalent to a permanent shock to a lower path. This leads to the question of why would either country 1 or country 2 choose free trade. The answer to this question depends on where you are on the decision tree and will be presented below. Before that, it is necessary to discuss further the rationale behind lower levels of consumption and wealth in free trade than in autarky. As we saw during the presentation of the autarky model, autarky happens when $\alpha = 0$ so that both countries are in fact producing with the sole intermediate y_3 . This results is a *de facto* single aggregate production function for the final good which takes as arguments the total factor productivity Φ parameter and the four endowments to the power $\frac{1}{4}$.

Under our assumptions, opening-up to free trade involves (via the allocation parameter

Figure 3.30: Constrained Steady-States as a function of asymmetry in free trade



Source: Author's calculation

α) the allocation of endowments across four intermediates. Intermediates being traded, comparative advantages materialise. It is critical that this feature in the production structure is not an artificial complexity, but the direct consequence of the assumption that comparative advantages are shaped by differences in endowments when trade is in intermediate good. The need to allocate factor endowments through a cost minimisation process results in lower overall productive efficiency. To be more accurate, free trade does rise the direct factor contribution to production, but this is more than compensated by the lower total factor productivity term²⁵. As discussed below in the section on robustness checks, this is not a consequence of the value of α , no value in the range $]0; 1[$ changes this result.

25. Factors contribution is put to the power $\frac{1}{4}$ in autarky and $\frac{1+\alpha}{4}$ in free trade, but the productivity term is Φ in autarky and $\Phi\alpha^\alpha(1-\alpha)^{\frac{1}{4}}$ in free trade.

These conclusions makes intuitive sense when one considers the complexities and coordination costs implied by setting-up the global supply chain. Those costs are usually modelled as transaction costs, but we believe that organisational costs are fundamentally different in nature from other costs, such a customs duties or shipping. Those costs can exist even in a frictionless, a-spatial model such as ours. Coordination costs are the main costs in a the world of the global supply chain described by Berger (2006). The production structure and its consequences for total factor productivity are therefore the explanation behind the counter-intuitive result that both countries are better-off in autarky. Still, the study of our scenarios allows us to offer some reasons for opening-up to trade despite the adverse effects on consumption and wealth.

IV.2 The impact of trade

Although opening-up to trade systematically reduces consumption and wealth, it should first be noted that the reduction is not uniform with asymmetry. In both CA and SC, consumption, produced capital, renewable resources and wealth losses are lower for high asymmetry steady-states than for low asymmetry ones. This result indicates that for both countries, the incentive to open-up to trade will be mostly felt in high asymmetry. Discussing country strategy will yield a matrix of likely outcomes, which depends mostly on the decisions in country 2. Tables containing the rates of change between the different settings are available in appendix F.

Under high asymmetry in autarky, country 2 is better-off undertaking structural change, as doing so allows it to compensate for the scarcity of produced capital and labour by accumulating labour. Under low asymmetry in autarky, as the disadvantage in labour and produced capital is minimal, country 2 is better-off pursuing a CA strategy, accumulating renewable resources to increase wealth and consumption. As for country 1, its situation is obviously the same under CA and SC.

It should also be noted that for both countries relative losses in wealth and consumption are higher when opening-up to trade in CA compared to SC. As an example, world consumption for $k = 1.25$ is reduced by 42% in between autarky and free trade in SC, but only by 38% in CA. This result illustrate a interesting situation for country 2. Should it decide to stay in autarky, it is better-off turning to structural change (SC). And once it chooses structural change, it faces a powerful incentive to open-up to trade: better production cost control.

For the same reason that SC makes more sense than CA for high asymmetry, making the transition from a high to a low asymmetry constrained steady-state is less costly with international trade. w_1 , e_2 and r_2 increase by less while w_1 , e_1 and r_1 decrease by more. Reduced

production efficiency means that consumption, wealth and produced capital also increase by less in the transition. As a consequence, consumers and producers face conflicting incentives regarding trade openness.

Therefore, once the initial negative shock is suffered, transition between constrained steady-states is made at a lesser cost under free trade and under positive short run shocks reducing asymmetry. There is decreasing loss with asymmetry when opening-up to trade. As a consequence, if a short run shock increases asymmetry as in scenario 1, then the impact is larger under free trade than in autarky. For example, in scenario 1 under SC, world consumption increases by 0.63% in free trade and 0.50% in autarky. Asymmetrical variations in asymmetry have a greater positive impact in free trade than in autarky.

To summarise, although opening-up to trade comes with a strong initial negative shock, benefits can be expected afterwards. Transition under a permanent shock to low asymmetry is made at a lesser cost, even with temporary shocks reducing asymmetry in a non symmetrical fashion. Conversely, if those temporary shocks increase asymmetry (as in scenario one) then income, wealth and produced capital gains are higher under free trade, which is consistent with the original observation that free trade is less of a disadvantage when asymmetry in endowments is high.

Country 2 is therefore in an awkward situation. It is (in high asymmetry) better-off in SC, and once it chooses SC, it will face incentives to open-up to trade to obtain cost control gains from trade as it reduces asymmetry through investment. As the country reduces asymmetry its incentives to stay under (CS) free trade fade since reduced asymmetry makes the CA scenario more competitive. Therefore, for country 2, the best strategy starting in high asymmetry is to turn to SC, open-up to trade to reduce asymmetry at a lower cost and turn back to CA and autarky when “enough” reduction in asymmetry took place. We would estimate that moment as the moment where consumption is higher in CA than SC, that is between $k = 1.55$ and $k = 1.60$.

It is however unlikely that country 1 will accept this. Country 1 is not affected by the decision between CA and SC in autarky but should it decide to open-up to trade the decision of country 2 between those two possibilities becomes critical. As is the case for country 2, country 1 should decide to open-up to trade to exploit the “cost control” property when in high asymmetry. Contrary to country 2, once under (SC) free trade, country 1 has an incentive to stay under free trade until the two countries reach factor price equalisation (FPE).

We should first stress that the IE equilibrium brings mild overall gains for the world, but that those gains are very unequally shared. This is the “burden sharing” advantage of trade.

In both CS and IE, adjustment to short run shocks depends on the factor hit by the shock. If the factor is a source of comparative advantage for the country, then the shock is positive and both countries win in consumption, wealth and produced capital. But if the factor is not a source of comparative advantage, then the country hit by the shock benefit from it while the partner loses out. Beyond the price reaction, this is because trade creates interdependence and allow access to factors outside of the country. Trade is therefore a powerful tool to alleviate scarcity and create common interests and benefits between countries. As a consequence, any event reducing this needed interdependence (as in scenario 2 and 3) has negative consequences for the suddenly “less needed” partner.

This feature is especially striking during the transition from CS to the integrated equilibrium (IE) in SC. While the world gains from the transition are very mild (0.17% increase in world consumption, 0.16% increase in wealth and 0.65% increase in produced capital) they are much larger for country 1 (respectively 2.77%, 4.11% and 14.01%) and turn to losses for country 2 (respectively -2.3%, -3.69%, -17,20%). When the world turns into an integrated economy, although it allows equalisation in consumption levels, this is made for the benefit of the country relatively well endowed in the factor desired by both countries. Then, as long as FPE is maintained, temporary shocks create movements in the production structures of countries²⁶ while maintaining consumption at equal levels in both countries.

As a consequence, country 1 is *relatively* better-off if country 2 a) does not revert to CA and b) stays under free trade so that the cost control property of international trade is still enforced. Then, as both countries move the IE equilibrium, large gains can be expected for country 1 when factor prices finally equalise, even if country 2 losses out. We believe this scenario clearly illustrates the problem of the time horizon. Should both countries consider the long run and all the possible constrained steady-states, country 2 would revert to autarky and CA as asymmetry is reduced. Country 1 would do the same as it would also be *absolutely* better-off even if it loses out in *relative* terms.²⁷ Alternatively, when considering only the most immediate (in terms of time horizon) constrained steady-states (as in the scenarios), country 1 has every incentive to keep the free trade agreement. Assuming that unilateral break away is impossible, country 2 is then stuck in a scenario that is not adapted to its structure of endowments.

It should finally be noted that although the burden of adjustment is shared in trade, it is not shared the same way in CS and IE. Scenario 4 is especially telling in that respect. In CS, scenario 4 results in larger losses across variables of interest for country 2 than for country 1. One can think of the oil shocks of the 70's as the perfect illustration of this situation. But

26. Although the production pattern being indeterminate, we only see the consequences on produced capital)

27. Under the lowest possible asymmetry ($k = 1.01$) in CA, consumption in country 1 is 61% of consumption in country 2 in autarky, when it would be 64% of consumption in country 2 in SC.

in IE, although wealth is reduced by more in country 2 because of the exogenous shock, the endogenous response is stronger in country 1 (-6.86% for produced capital) than in country 2 (-4.76%) for produced capital. The “Integrated Economy” balances the equilibrium at the world level, which in the context of depleting exhaustible resources, means transferring the burden of adjustment to areas not subject to the new exogenous constraint. This is the finest example of what interdependence and burden sharing imply under free trade. When interdependence is maximised as in IE, even if country 2 might be better-off in autarky, interdependence offers a form of protection that can not easily be dismissed.

The above conclusions do suggest that the opportunity to open-up to trade is strongly dependent on the state of asymmetry and the state of the potential partners. A number of archetypal countries emerge from the decision tree and the examination of the actual impact of trade, listed below:

- Countries characterised by low asymmetry and an advantage in K_e and K_r . Those countries will favour continued accumulation and maintenance of their comparative advantage (CA) and autarky.
- Countries characterised by high asymmetry and an advantage in K_e and K_r . Those countries are likely to choose SC and autarky and might be willing to choose free trade if partners are also characterised by high asymmetry under pressure of the production sector. This could help balance the strong negative shock with rapid gains from trade.
- Countries characterised by high asymmetry and an advantage in K_l and K_p . Those countries are likely to choose free trade, as the initial negative shock associated with openness is the lowest possible and the benefits from access to scarce resources are likely to be high.
- Countries characterised by low asymmetry and an advantage in K_l and K_p . Those countries are likely to choose autarky and would only open to trade in case of domestic scarcity risks. In that situation, they could share the burden of adjustment to scarcity shocks with their trading partner, especially under IE.

Those categories are arguably vague and demand an arbitrage between the need to access foreign factors (when domestic factors are relatively scarce) and the losses incurred when opening-up. What is certain is that a country 2 type in CA and low asymmetry has no incentive to open-up to trade and a country 1 type and high asymmetry in endowments has every possible incentives, especially if it can trade with country 2 types in SC. If relative position matters, decisions to open-up are more likely in SC as this is the ultimate guarantee of convergence in consumption levels in IE.

Those results, although quite original are not completely detached from the literature. The

problem of consistency between a given starting point and an optimal/sustainable path chosen *ex nihilo* is already discussed by [Bazhanov \(2010\)](#). Our results also have parenthood with the open economy Hartwick rule although we stress the importance of domestic endowment reaction to an evolution of world prices. Considering world prices without the possibility of a breakdown in FPE also misses the possibilities introduced by differences in country factor prices for sustainability.

We also show how asymmetry matters in international trade and sustainability. International trade does not necessarily provide incentives to reduce asymmetry or at least not in the best possible manner from a country perspective. This clearly relates to the subsidiarity principle as defined in [chapter 1](#). We believe our results provide a rationale for low scale (regional or national) management of instruments of wealth and stress the need to shield at least some of those instruments from international trade. Interdependence has its benefits: cost control in the production sector and “burden sharing” in the event of asymmetric shocks. Nevertheless, interdependence does not foster structural change or reductions in asymmetry. Indeed, interdependence may even prevent factor intensity reversal or reduce reinvestment via movements in global prices.

The application of the subsidiarity principle therefore calls for a form of protectionism in the interest of structural change. This protectionism should be centred on critical instruments of wealth and designed to promote a reduction in asymmetry. Our results also point at an interesting consequence of interdependence. As is well-known in the trade literature, the [Balassa \(1961\)](#) scale describes economic integration from the preferential trading area to the full economic integration. We believe that sustainability concerns could provide a new rationale for economic integration. If free trade results in undesirable specialisations while “burden sharing” is needed (especially if strategic resources are involved) then economic integration may make sense. It would also make sense as integration may reduce coordination costs, so that trade liberalisation becomes a more attractive possibility.

This possibility is quite interesting on paper and would also add a layer on the subsidiarity framework we presented in [chapter 2](#). It would reduce the “grey area” of international trade and promote international institutions for international instruments of wealth management. There is however an issue, well illustrated by the current difficulties of the European union. The perimeter of economic integration should include in our model countries that have quite asymmetric distributions in endowments. Still, those countries should have close enough institutions and norms to give legitimacy and enforcement power on the newly formed international institutions. This balance between high enough asymmetry in endowments and institutional sameness is not easily found. We discuss it further in the next chapter (see [4 section III](#)).

International trade is therefore a powerful tool of cost control and a way to share the burden of adjustment to exogenous shocks. This means both spreading benefits and sharing losses, under different patterns depending on the trade regime. In the final section we discuss how sustainability rules should be amended using our results.

IV.3 Consequences for ANS and wealth management

As presented in chapter 2, there are numerous reasons to rethink the role of trade in sustainability. Our model shows that even before starting to include concerns regarding intragenerational equity, uncertainty, precaution and option value, international trade has an impact beyond capital gains.

We explored in this model the impact of structural change on sustainability. Our results are certainly limited by methodological choices inherent to our production structure and HO modelling. Nevertheless, we kept the main features of sustainability issues intact. As in [Dasgupta and Heal \(1979\)](#), all factors are required in production. We also study the consequences of expected substitution between factors as a consequence of the depletion of natural capital. Since we use an HO structure of trade, our results are not unrelated to the composition, scale and technique effects in [Copeland and Taylor \(2003\)](#). They nonetheless go beyond those findings, mostly through the introduction of dynamic interdependence with four factors. Our results finally shed additional light on the debate on the “responsibility for depletion” initiated in the works on virtual sustainability by [Proops et al. \(1999\)](#), [Atkinson and Hamilton \(2003\)](#) and [Atkinson et al. \(2012\)](#).

We focused on the impact of trade on structural change, monitoring the evolution of consumption and wealth. We also investigated the composition of wealth related to concerns about strong sustainability. Our first conclusion is that international trade of resources intensive goods is detrimental to wealth, under our assumption regarding the structure of production. Domestic management of wealth, through the shortest possible supply chain is the best outcome for wealth (and consumption). An even better outcome is obtained when closed economies focus on the endogenous management of the factor they are relatively well endowed with, as in the CA case. Autarky or quasi-autarky is however not the rule. Once interdependence exists it should be properly accounted for, for the best possible wealth management (in line with the Hartwick rule).

We show how international trade, via factor prices (either domestic or world prices) changes the incentives for factor use. In our setting capital gains are endogenous as in [Hartwick \(1995\)](#).

Capital gains materialise in the evolution of factor price ratios when going from low to high asymmetry in country 2. Conversely, capital losses are observed in country 1 for natural capital as it becomes more abundant. Therefore, accounting for capital gains is only one side of the story of international trade. What is needed is the implicit assumption build-in in our scenario. Country 2 needs *domestic* reinvestment into produced capital or labour and country 1 needs *domestic* reinvestment into natural capital to expand it, as reliance on labour is reduced.

Hence, Adjusted Net Savings (ANS) should be corrected for structural change. Extra savings resulting from trading activities should be set aside to finance the development of endogenous capital and substitution in exogenous variables (as in the transitional dynamics we present). We hope it is by now clear that those are larger than the capital gains previously identified in the literature. As capital gains are notoriously hard to estimate, it is worth considering how to estimate those gains from trade related to structural change. Our model yields a simple answer to this question. Those gains are equal to the amount saved in free trade compared to autarky in the transitional dynamics. They are equal to the “cost control” amount we identified above. Would the considered country still be in autarky, it would encounter neither the efficiency losses from going to trade, neither the cost control gains. As a result autarky prices are all higher.

An estimate of the extra savings can be provided using the figures from the transitional dynamics. Let us consider the SC case, in transition from low to high asymmetry. We estimate that w_1 increases by 41% less and e_1 and r_1 decrease by 4% more in free trade compared to autarky. Multiplying those percentage by the low asymmetry equilibrium quantities lead to gains from trade equivalent to 8.02% of steady-state income for country 1. The same calculation yields a value of 5.48% of steady-state income in country 2. Those figures would represent a significant addition to ANS as ANS for most countries are in a range of 3 to 10% of income. It should also be noted that this magnitude would help reconcile ANS with more pessimistic indicators of sustainability such as the ecological footprint. It suggests that both country 1 and country 2 types of countries are currently not saving enough.

Saving those gains from trade would also provide a first solution to the debate about responsibility. It should be stressed that this solution rests upon the assumption of perfect substitutability, as it implies that capital not accumulated (or depleted) in country 2 and imported in country 1 is reinvested in domestic capital there and vice versa. This solution involves international compensation between countries and therefore shared responsibility. It makes sense even in terms of patterns of trade, as reduced asymmetry will diminish the volume of trade as it diminishes the rationale for trade (as in any HO model). As countries use trade to slowly level their endowments, trade becomes unnecessary and die out. The ironic but expectable result is that sustainable trade is working for its own extinction.

This does not mean however that all trade will disappear. It is time to stress again that our model explores international trade in the context of sustainability under one motive for trade. Other rationales for trade play a big role in today's organisation: trade based on differences in productivity and trade based on variety gains. Trade can and will persist, as extensively documented in the literature, for as long as productivity differences will persist. So will trade flows resulting from the willingness to pay for variety. But those flows are in our view fundamentally different from flows of intermediate goods generated by structural change and creating the global supply chain as we experience it today. Our model singles out the gains from trade arising from asymmetry in endowments as the only gains needing compensation on economic grounds. It is still open to discussion whether other forms of trade require compensation based on a broader or amended definition of sustainability.

The final point of this long investigation has to do with the somewhat peculiar nature of the gains from trade in our model. Those are relative gains from trade, generated by the different manifestations of structural change compared to autarky. Our model actually predicts losses from trade when going from autarky to free trade. Still, the finding that gains from trade liberalisation can be expected is one of the most robust in economics, resilient to several tests and model specifications. Based on the results of our model we stick to the position that trade based on the international division of the productive processes does not generate gains in the context of constant or decreasing returns to scale.

This observation leads us to believe that the main driver of the massive expansion of the global supply chain is the materialisation of increasing returns to scale in production. In the next and last chapter, we extend our analysis to this case, discussing the sources of increasing returns to scale in production and the impact of their existence on sustainability. We end this presentation with a set of robustness tests on our parameters, before concluding.

IV.4 Robustness and sensitivity checks

In this section we focus on the impact of the values taken by the parameters on the stability of the model. We do not perform any additional test on the values for the asymmetry on endowments. The values represented in the figures in section III.4 already cover the widest range of values for which all the models (autarky, complete specialisation and integrated equilibrium) are stable. Stability tends to break down for the CS model in the CA scenario if the parameters are unchanged compared to lower asymmetry. Still, as our model is not calibrated on real world data, this does not represent a challenge to the validity of our conclusions. If anything, it suggests that the main functional relations (utility, production, etc.) are not stable across

different phases of structural change.

We focused our tests on the values of the parameters. The parameters ρ and δ have been calibrated as to be realistic, but their impact on our results is unambiguous. Higher δ values increase produced capital depreciation so that the steady-state values for produced capital, consumption and wealth are lowered for both countries and any level of asymmetry. Conversely, higher ρ values increase the “bonus” associated with renewable resources. As a consequence, steady-state values for renewable resources, consumption and wealth are higher in both countries. As country 1 is relatively more intensive in produced capital is it more sensitive to variations of δ . The same is true for country 2 with ρ .

The two parameters we tested more thoroughly are α and Φ . We use the CS model to conduct our robustness tests as it is the most comprehensive one. As discussed above, α determines the allocation of factors between intermediate goods (see section II.1.1). Higher α values make for a bigger share of endowments allocated to the intermediate goods forming the comparative advantage in both countries (goods y_1 , y_2 , y_4 and y_5). As a consequence, the volume of trade is likely to be bigger. To test the impact of the value of α on steady-states values we computed the steady-states corresponding to asymmetries $k = 1.19$ (for both IE and CS equilibria) and $k = 1.75$ (in CS only). We run the test for two alternative values for α . Results are displayed in tables 3.6 and 3.7.

Table 3.7: Stressed values for α in the IE model

Robustness checks	benchmark $\alpha=0,15$	$\alpha=0,45$	$\alpha=0,1$	variation for $\alpha=0,45$	variation for $\alpha=0,1$
c	0,68	0,4684	0,7787	-31,12%	14,52%
W	8,0464	7,4365	8,3309	-7,58%	3,54%
Y	0,8001	0,5616	0,9113	-29,81%	13,90%
K_p	2,0464	1,4365	2,3309	-29,81%	13,90%
K_l	2	2	2	0,00%	0,00%
K_e	2	2	2	0,00%	0,00%
K_r	2	2	2	0,00%	0,00%
c_1	0,34	0,2342	0,3894	-31,12%	14,52%
c_2	0,34	0,2342	0,3894	-31,12%	14,52%
W_1	4,1338	3,7234	4,3252	-9,93%	4,63%
W_2	3,9126	3,7131	4,0058	-5,10%	2,38%
Y_1	0,4104	0,2865	0,4682	-30,18%	14,08%
Y_2	0,3897	0,2751	0,4431	-29,41%	13,72%
$K_{p,1}$	1,3238	0,9134	1,5152	-31,00%	14,46%
w	0,1	0,0702	0,1139	-29,81%	13,90%
p	0,0977	0,0977	0,0977	0,00%	0,00%
e	0,1	0,0702	0,1139	-29,81%	13,90%
r	0,1	0,0702	0,1139	-29,81%	13,90%
$K_{p,2}$	0,7226	0,5231	0,8158	-27,62%	12,88%

We observe that higher α values systematically reduce consumption, wealth and income in both countries. Lower α values increase the steady-state levels of those key variables. Interestingly, the overall reduction (at the global level) is the same in both CS and IE, but in CS countries are not affected the same way. Country 2 benefits (resp. suffers) the most from lower (resp. higher) α values. The fact that the global impact is the same in CS and IE is proof that the model is consistent. The fact that country 2 is more impacted by variations in α is also consistent with our interpretation of the results. As country 2 has higher steady-states consumption and wealth values, it is more impacted by evolutions in the volume of trade and world prices. As seen through the scenario, country 1 benefits most from the “burden sharing” property of international trade.

We follow the same strategy for the parameter Φ (Tables 3.8 and 3.9). Φ is a measure of total factor productivity in the final good production function. We observe that lower Φ values reduce consumption, income and wealth in all three settings (autarky, IE and CS). Conversely, higher Φ values lead to higher consumption income and wealth. As with α , the global impacts are similar under the CS and IE models, showing the robustness and consistency of the model. As expected, autarky variations are higher. This value reflects the direct impact of Φ in that model, when in CS and IE settings the impact of Φ is reduced by coordination costs.

Table 3.8: Stressed values for Φ in the CS model

Robustness checks	benchmark $\Phi=0,607$		$\Phi=0,7$		$\Phi=0,4$		variation for $\Phi=0,7$		variation for $\Phi=0,4$	
	k=1,19	k=1,75	k=1,19	k=1,75	k=1,19	k=1,75	k=1,19	k=1,75	k=1,19	k=1,75
c	0,678886	0,523022	0,827279	0,638788	0,37651	0,28713	21,86%	22,13%	-44,54%	-45,10%
W	8,03315	7,52359	8,45876	7,84253	7,16591	6,8737	5,30%	4,24%	-10,80%	-8,64%
Y	0,798345	0,620061	0,965465	0,749859	0,45781	0,355573	20,93%	20,93%	-42,66%	-42,66%
K_p	2,03315	1,52359	2,45876	1,84253	1,16591	0,873704	20,93%	20,93%	-42,65%	-42,65%
K_l	2	2	2	2	2	2	0,00%	0,00%	0,00%	0,00%
K_c	2	2	2	2	2	2	0,00%	0,00%	0,00%	0,00%
K_r	2	2	2	2	2	2	0,00%	0,00%	0,00%	0,00%
c_1	0,330835	0,196335	0,402633	0,238219	0,184534	0,110988	21,70%	21,33%	-44,22%	-43,47%
c_2	0,348051	0,326688	0,424646	0,400569	0,191976	0,176142	22,01%	22,62%	-44,84%	-46,08%
W_1	3,97036	2,95555	4,21326	3,10325	3,47541	2,6546	6,12%	5,00%	-12,47%	-10,18%
W_2	4,06279	4,56804	4,2455	4,73928	3,6905	4,21911	4,50%	3,75%	-9,16%	-7,64%
Y_1	0,394041	0,231129	0,476526	0,279512	0,225962	0,132541	20,93%	20,93%	-42,66%	-42,65%
Y_2	0,404304	0,388932	0,488938	0,470347	0,231848	0,223033	20,93%	20,93%	-42,66%	-42,66%
$K_{p,1}$	1,16036	0,705551	1,40326	0,853246	0,665408	0,404598	20,93%	20,93%	-42,66%	-42,66%
w_1	0,0953063	0,0394064	0,115257	0,0476554	0,0546534	0,0225976	20,93%	20,93%	-42,65%	-42,66%
p_1	0,0977408	0,0977408	0,0977408	0,0977408	0,0977408	0,0977408	0,00%	0,00%	0,00%	0,00%
e_1	0,103217	0,186413	0,124824	0,225436	0,0591898	0,106899	20,93%	20,93%	-42,65%	-42,65%
r_1	0,103217	0,186413	0,124824	0,225436	0,0591898	0,106899	20,93%	20,93%	-42,65%	-42,65%
$K_{p,2}$	0,872793	0,818043	1,0555	0,989284	0,500502	0,469106	20,93%	20,93%	-42,66%	-42,66%
w_2	0,105318	0,319825	0,127364	0,386774	0,0603944	0,183403	20,93%	20,93%	-42,66%	-42,66%
p_2	0,0977408	0,0977408	0,0977408	0,0977408	0,0977408	0,0977408	0,00%	0,00%	0,00%	0,00%
e_2	0,0981887	0,0654341	0,118743	0,0791315	0,0563063	0,0375231	20,93%	20,93%	-42,66%	-42,66%
r_2	0,0981887	0,0654341	0,118743	0,0791315	0,0563063	0,0375231	20,93%	20,93%	-42,66%	-42,66%

Table 3.9: Stressed values for Φ in the IE model

Robustness checks	benchmark $\Phi=0,607$	$\Phi=0,7$	$\Phi=0,4$	variation for $\Phi=0,7$	variation for $\Phi=0,4$
	k=1,19	k=1,19	k=1,19	k=1,19	k=1,19
c	0,6789	0,8287	0,3772	22,06%	-44,44%
W	8,0332	8,4748	7,1735	5,50%	-10,70%
Y	0,7983	0,9676	0,4588	21,19%	-42,53%
K_p	2,0332	2,4748	1,1735	21,72%	-42,28%
K_l	2	2	2	0,00%	0,00%
K_e	2	2	2	0,00%	0,00%
K_r	2	2	2	0,00%	0,00%
c_1	0,3308	0,4143	0,1886	25,24%	-43,00%
c_2	0,3481	0,4143	0,1886	19,04%	-45,82%
W_1	3,9704	4,422	3,5466	11,37%	-10,67%
W_2	4,0628	4,0528	3,627	-0,24%	-10,73%
Y_1	0,394	0,4974	0,2331	26,23%	-40,83%
Y_2	0,4043	0,4701	0,2257	16,29%	-44,19%
$K_{p,1}$	1,1604	1,612	0,7365	38,92%	-36,52%
w	0,0953	0,1209	0,0574	26,90%	-39,83%
p	0,0977	0,0977	0,0977	0,00%	0,00%
e	0,1032	0,1209	0,0574	17,17%	-44,44%
r	0,1032	0,1209	0,0574	17,17%	-44,44%
$K_{p,2}$	0,8728	0,8628	0,437	-1,14%	-49,94%

A final comment should be made on the autarky model (figure 3.10). For lower values of Φ we observe that steady-state produced capital, consumption and wealth fall in country 1. However, in country 2 we see an increase in produced capital and wealth and an increase in steady-state consumption for the low asymmetry steady-state. This seemingly odd result is explained by the fact that this is the CS model. As productivity is reduced, all endowments becomes *de facto* scarcer. As a result country 2 has to invest more into produced capital to obtain the same contribution from the factor. Therefore, in high asymmetry consumption falls while steady-state wealth and produced capital are higher.

When asymmetry is lower, the basic mechanism is the same except that the price reaction to lower productivity is milder from reduced asymmetry. As a consequence, the representative agent increases consumption as well as wealth and produced capital. This mechanism could be expected from the bell-shaped evolution of consumption with asymmetry in the model (see figure 3.16). It stresses the importance of considering asymmetry in endowments in a dynamic setting. This final remark concludes our presentation of the robustness checks for the model.

Conclusion

In this chapter we offer a review of dynamic trade models, highlighting the most recent attempts to mesh together dynamic trade models and sustainability/environmental concerns (Atkinson et al. 2012, Bogmans and Withagen 2010, Van der Ploeg 2010). We stressed how a dynamic model for sustainability assessment, taking into account both the distribution of endowments and the price regime (endogenous/exogenous) was missing. Based on the definition of open economy sustainability in chapter 2 we insist that such a model should consider the consequences of interdependence, structural change and asymmetry in a range of instruments of wealth to provide lessons for sustainability. We then propose as a first step towards a comprehensive model, a dynamic Heckscher-Ohlin (HO) model with 2 countries, 5 goods and 4 factors. The model is based on a production structure adapted from Cuñat and Maffezzoli (2004).

Under this structure, international trade of the 5 intermediates goods takes place when countries open up to trade. We find international trade to reduce consumption and wealth, an unorthodox result. This feature of the model illustrates the dilemma for sustainability associated with international trade, the choice between diversification and specialisation. In autarky, all instruments of wealth enter production in a symmetric manner. This is a consequence of our assumption that all the instruments of wealth are equality important and needed in production. Under free trade, production needs to be reorganised around intermediate goods as those goods are relatively intensive in one instrument of wealth. This provides the rationale for trade, but decreases the overall efficiency of production as production factors now needs to be split between five sectors. Hence, international trade has an important impact on the use of domestic instrument of wealth: this is a trade-induced composition effect.

We observe that in line with standard HO theory, higher asymmetry in the distribution of wealth provides a greater incentive to trade. The larger the potential productive reorganisation, the larger the gains from trade. All countries, regardless of their comparative advantage should therefore strive to reduce asymmetry in endowments. This reduction can be obtained either by reinforcing the country's comparative advantage (the CA scenario) or by undertaking structural change (SC), substitution of produced capital for natural capital. We find that choosing one of those possibilities against the other will have an impact on the incentive to liberalise trade.

The decision to pursue one strategy against the other should be made depending on the level of asymmetry. If asymmetry in endowments is low then the exhaustible resources intensive country (country 2) has no incentive to liberalise trade and will be better-off pursuing the CA scenario. Country (relatively intensive in labour and produced capital) is then in the worst

relative situation although it is in *absolute* terms better-off than under high asymmetry in endowments. If asymmetry in endowments is high, country 2 is better-off pursuing the SC scenario. It then makes sense to liberalise trade as trade makes the transition to low asymmetry constrained steady-states less costly, even if both countries face an initial strong negative shock.

Once engaged in international trade, it is in country 2's best interest to return to autarky as soon as asymmetry in endowments is reduced enough. The best scenario would be for country 2 to revert to the CA case. Nonetheless, country 1 would not agree to end the trade agreement as it would end-up *relatively* worse-off in autarky and would face a relatively higher cost to pursue the reduction of asymmetry. International trade allows both countries to share the burden of asymmetric shocks, a property that benefits country 1 the most in case of symmetric shocks. If shocks are asymmetric, the country where the shock takes place is most affected in the complete specialisation (CS) trade setting. If asymmetry is low enough for the integrated equilibrium (IE) to be enforced, then the partner country (i.e. the country where the shock did not take place) is most affected.

Those results stress how international trade brings interdependence, with important consequences for sustainability. International trade shapes the distribution of instruments of wealth in all trading countries, encouraging specialisation to generate gains from trade. Investment and depletion decisions do not depend solely on domestic factors but also on the situation of the trading partners. Although we assume that both countries aim for a reduction in asymmetry, our scenarios illustrate how country specific shocks will impact positively or negatively sustainability in all the trading countries. As a consequence, sustainability assessment cannot afford to ignore the dynamics of the international environment to assess a given country course. A diagnosis on the rationale for trade liberalisation (or trade restriction) should be applied.

We also consider how Factor Price Equalisation (FPE) increases interdependence by enforcing a common price system. Convergence in consumption levels can be reached under SC with FPE, but it costs both countries compared to autarky. We also find the impact of shocks to be higher and FPE to be likely to break down considering the relatively low level of asymmetry for which it can occur. From a sustainability perspective, international trade should therefore be managed depending on the incentives for domestic reinvestment. Opening up to trade without considering either the global environment or the likely resulting domestic reinvestment path paves the way for lower wealth and consumption.

The timing of trade liberalisation is critical to its success. Our results stress that countries should be ready to withstand the initial negative shock and makes the most of the "burden sharing" property of trade. This suggests that entering trade might not be the best option for every country with every potential partner at all time. Our results show that trade is

more profitable when implemented between country with asymmetric distributions but the same development strategy. Hence, our results provides a rationale for economic integration between dissimilar countries. This result is interesting in the light of the recent difficulties in economic areas trying an integration “amongst equals”. From a sustainability perspective, it seems more promising to undertake liberalisation between countries that are institutionally similar but dissimilar in endowments. This point is debated in chapter 4 section III.

Since international trade creates interdependence, trade liberalisation should always be managed using corrective institutions. Some trade flows should be limited or banned if they work against sustainability. We stressed in chapter 2 how the subsidiarity principle and the need to preserve diversification could legitimise the use of trade management instruments to foster early attempts to diversify. In a similar vein, we believe that trade management instruments could be legitimately used to protect trade relations that are sustainably managed and work for a reduction of asymmetry. Even before discussing exterior tariffs, the negotiation of preferential agreements on sustainability grounds should be undertaken.

In the meantime, a more accurate picture of sustainability on a country-by-country basis can be obtained amending the Adjusted Net Savings (ANS). We saw how a reduction in asymmetry in the distribution of endowments was less costly in free trade than in autarky. Those gains constitute the main rationale for opening-up to trade in high asymmetry. We propose to save those gains from trade to finance structural change. Those resources can legitimately be mobilised for structural change, as an alternative autarky path would have been to the benefit of the wider society. It is therefore sensible that the gains from trade liberalisation are uses for to reduce asymmetry and to improve social utility. Trade management instruments could be used to return those gains to the social planner.

Sustainability demands a differential treatment for the gains from trade. We propose to save and reinvest the gains from trade-induced specialisation. Those are the only gains from trade in our model. Saving and reinvesting those gains is especially important over concerns regarding the future level of real substitutability between instruments of wealth. In that sense, our model is the theoretical background behind the measures of “virtual sustainability”. High rates or resources embodied in trade flows are not *per se* a problem. But they clearly are a strong message of trade-induced un-sustainability when domestic investment is inadequate.

Other sources of comparative advantage exist in the real world, generating other kinds of trade flows. The pattern of trade in our model is inter-industry: countries trade intermediate goods from different sectors. Still, the majority of international trade is conducted today on an intra-industry basis. Intra-industry trade is based on the existence of economies of scale. In the next chapter we investigate the consequences of increasing returns to scale on our

recommendation regarding the reinvestment of the gains from trade.

Inter- and intra-industry patterns of trade are associated with different gains from trade. We saw a qualitative analysis of trade flows is needed in the context of uncertainty regarding substitutability. To clarify the respective role of inter- and intra- industry trade in structural change we proceed to study the links between resource abundance and the nature of trade. Our analysis provided a renewed rationale for economic integration. Still, our results are based on countries that are similar in every respect but the distribution of their endowments. We therefore investigate further the links between international trade and institutional settings, using natural experiment to see how institutional similarities matter to explain sustainability performance. Those results should allow us to sharpen our recommendations regarding trade liberalisation and sustainability.

CHAPTER 4

Increasing returns to scale and institutions: Sustainability and interdependence

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Introduction

I^N chapter 3, we present an amendment based on the gains from trade for Adjusted Net Savings (ANS). This amendment is based on the efficiency gains from trade resulting from lower factor prices in the process of convergence towards low asymmetry equilibrium. This theoretical model also yielded interesting insights into the respective positions of country one types countries (relatively intensive in labour and produced capital) and country two types (relatively intensive in exhaustible resources) countries.

Comparisons of the CA and SC scenarios show that when countries do not exert control on the accumulation of the same factors, resource-rich countries are better-off managing exhaustible resources in autarky. The situation is different when both countries are accumulating the same kind of capital. In that case, free-trade with a view on an integrated equilibrium might be promising especially if, based on other sources of gains from trade, free trade yields wealth and consumption gains compared to autarky. Finally, we insisted on the role of asymmetry in endowments. Reduction in asymmetry is in any situation a desirable outcome, as it systematically yields higher consumption and wealth steady states levels in the setup of the model.

Under constant returns to scale (CRS), no productivity gains from allocating more resources to the comparative advantage goods can make free trade more interesting (see model in chapter 3). The idea that international trade may result in a costly reorganisation of production so that countries are better off in autarky leads to many questions. Should this theoretical prediction be empirically validated, the commonly observed gains from trade (Bernhofen and Brown 2005) would constitute a puzzle. What kind of gains may make free trade more interesting than autarky?

In this chapter we start by providing a potential source for those gains from trade, based on the international organisation of production under increasing returns to scale (IRS). When the international division of the productive processes generates IRS, trade should be beneficial as IRS may outweigh the additional costs from the domestic reorganisation of production to exploit comparative advantages. The role of IRS in international trade has been largely investigated from early empirical evidence in Leontief (1953) and Grubel and Lloyd (1975) to the theoretical formulations in Dixit and Stiglitz (1977), Krugman (1980) and Lancaster (1980).

The sources of IRS in international trade can be internal to the firm. In this situation agglomeration forces push for the concentration of economic activity (Krugman 1991) to benefit from those internal economies of scale. Conversely, external economies of scale can be derived

from the size of the market. A final source of IRS in international trade comes from the international division of productive processes (IDPP) as presented in Berger (2006) or Friedman (2005). The formation of a global supply chain by the IDPP is largely a consequence of the IRS derived from the increased division of labour. This is the situation that is most relevant for sustainability studies.

We start this chapter by presenting in the context of sustainability the Ethier (1982) model of international trade. This model stresses the difference between “national” returns to scale resulting from geographical concentration of production and “international” returns to scale resulting from the international division of labour. The framework set by Ethier shed light on some of our findings in chapter 3. It shows how increasing returns to scale are going to be more important as asymmetry is reduced, providing a rationale for opening-up to trade even if autarky is more appealing in the short-run. Convergence to less asymmetrical steady-states will yield consumption and wealth gains. This brings back our model in chapter 3 in the mainstream conclusions of the trade literature, although estimates of the extra gains from trade are not studied.

Based on our exploration of the CA scenario in chapter 3 and the Ethier (1982) model we assess the importance of another feature in the model. Ethier shows that intra-industry trade is associated with complementarity (see proposition 11). This means that countries converging towards what we described as low-asymmetry steady-states should have a predominantly inter-industry trade structure. Indeed, convergence reduces the incentive for inter industry trade as differences in endowments fades. In Ethier’s setting, IRS do not impact the domestic factor allocation as set by usual HO technology. Still, they do change factor prices which will have a impact on the dynamics of accumulation.

The impact of IRS can be assimilated to a positive externality, making market prices diverge from shadow prices. Given that a country relies heavily on some factor endowments without reducing asymmetry, then its trade will remain dominated by inter-industry trade in goods intensive in the considered endowments. In the setting of chapter 3 this means that a country failing to follow the Hartwick rule will also have a strong interindustrial trade pattern in natural resource intensive goods. If this relationship holds over time, international trade will reinforce this pattern and can play against sustainability, as assessed by domestic conditions.

To explore this insight, we turn back to the logic of the scenarios and the notion that countries may differ in nature depending on which kind of factor are primarily accumulated. As in the CA scenario, we use the literature on the resource curse to explore the behaviour of resource rich countries which have an incentive to accumulate natural resources (i.e. rely more on the stock in total output) as in a Dutch Disease scenario. We could argue against this in a

dynamic perspective using our model. Still it is rational at least in the short run to rely on the comparative advantage from natural resources.

The literature on the resource curse stress that this may lead to institutional issues, so that trade-induced specialisation and institutions may interplay into wasting some of the natural resources rent. We argue that although the literature has so far focused on the role of institutions and considered trade incentives as given if not optimal, the two are impossible to disentangle in a dynamic perspective. One should therefore not discard the possible need to act on trade flows so that unsustainable consumption of natural resources rent can be avoided.

We illustrate this point by investigating empirically how country 2 types countries in CA (fostering its comparative advantages) seem to face empirically two paths towards a reduction of asymmetry. Our archetypal country may either reduce asymmetry through depletion of natural capital prior to accumulation of another form of capital. It then struggles to accumulate produced capital as a resource poor country. It could instead increase its endowment in produced capital by sound reinvestment of the rent, as in the Hartwick rule. In this second scenario, reduction in asymmetry is obtained by increasing the share of other instruments of wealth, not by diminishing the amount of the abundant instrument, natural capital.

We present those two paths using the trade profile of resource abundant countries, demonstrating how the one-way versus two-ways nature of trade in resource intensive goods may be used as an indicator of the path followed by a resource rich country. We show that countries engaged in possible excessive depletion tend to engage in one-way trade in natural resources intensive goods. An indicator of sustainable use of natural resources is therefore two-ways trade in natural resource intensive goods. This empirical test stress the role of trade flows as an indicator of sustainability and the fact that trade flows shape as much as they are shaped by domestic conditions, notably specialisation.

The feedback mechanism by which trade is shaping institutions and setting the pattern of resources allocation still evades us. What is missing to estimate the respective impact of trade and institutions on resource allocation is an estimate of the weight of institutions on allocation. This is the famous theory of co-evolution between economic conditions and institutions ([Arrow et al. 2010](#)). Establishing such a theory is beyond the scope of this chapter. Still, we propose a natural experiment which might help with shaping such a theory. We present a sustainability assessment for the Russian Federation and we propose a comparison between Russia and its neighbours. We use this assessment to stress the importance of counterfactual studies ([Hamilton et al. 2006](#)) as policy design instruments and indicators of sustainability.

We conclude that institutions are likely to have the strongest influence on the dynamic of

development, as captured by ANS. Therefore, resource rich economies are better understood by accounting for their regional characteristics (culture, politics and history) than by simply focusing on the rent from natural resources. From this premise, it makes sense to account for institutions in the dynamic part of the theory and to save trade impacts for a period by period price setting mechanism¹.

In section I we present our analysis of the Ethier (1982) model and its implications for sustainability. Section II reviews briefly the findings of the literature on the Dutch disease and the resource curse to illustrate the role of intra-industry trade in sustainability approaches. Finally, in section III we present an application of sustainability tools to the Russian case, stressing the crucial role of institutions and the usefulness of counterfactual studies to assess sustainable development.

I The Ethier model: IRS and international trade

In chapter 3 we presented a model based on the international division of labour. This model, built on domestic Cobb-Douglas functions, exhibits constant returns to scale (CRS). We conclude that focusing on domestic consumption and wealth only, countries (regardless of the distribution of their factor endowments) should stay under autarky while undertaking structural change. This conclusion is based on the cost of developing sectors producing intermediate goods that will be traded to exploit comparative advantages.

This conclusion although strong and motivated is inconsistent with the reality of trade, which saw an increase in trade in intermediate goods, after the second world war, culminating in the formation of the global supply chain. As presented in Friedman (2005), the global supply chain was boosted by lower coordination costs induced by the new communication technologies and the internet. This latest wave of globalisation and economic integration started in the 1990's and did not abate before the 2008 financial crisis. Although the association of lower coordination and transaction costs, intra-industry trade and increasing trade flows are presented together as motives for the development of the global supply chain, the rationale for developing intra-industry trade is more confused.

Indeed inter-industry trade can make intuitive sense for the “consumption of services” from capital theory. If a given good providing unique services is not available in the domestic economy, it makes sense to trade to obtain it. The rationale for developing some elements of national

1. This setting would in fact be a more complex version of the model in chapter 3 if a unique and stable equilibrium can be found.

production against others or even abandoning some productions that are still in demand, already makes less sense. It may explain the popularity of explanations based on comparative advantages. As we discussed at length in previous chapters, the emerging sustainability field relied mostly on those analytical tools aggregated in the neoclassical trade theory.

Authors in the field were not so much interested in how trade generated interdependence in line with our analysis in chapter 3, but more in the way international trade affected the consequences of domestic shocks on the domestic economy. In chapter 2 we showed how this leads to the elaboration of the Copeland and Taylor model for the composition, scale and technique effect, and to the assimilation of trade to productivity shocks over long intervals.

Intra-industry trade came as a puzzle for the first authors confronted to its rise as a share of world trade. It came as a new reason for critique to authors already opposing the logic of the comparative advantage (Daly 1992). Authors seeing any reduction of trade flows as a gain for the environment welcome reductions in intra-industry trade, perceived as especially malignant and harmful to both citizens and the environment. Authors less critical of trade looked for the consequences of trade on the divide between inter and intra-industry trade. Cole and Elliott (2003b), working on the pollution haven hypothesis, investigate the role of pollution regulation in explaining the weight of intra-industry trade.

The pollution haven hypothesis is intimately related to intra-industry trade as both share a common motive: increasing returns to scale (IRS). Further difference should be introduced between intra-industry trade in intermediate goods and intra-industry trade in consumption goods. When considering trade in intermediates, IRS in the production of a dirty good help in creating a pollution haven and keep the country specialised despite rising income. Even in the literature on trade and the environment, where several trade models and settings have been applied to the pollution haven hypothesis, the exploration of the potential impact of intra-industry trade remains limited.

IRS are the basis for intra-industry trade. To understand why, one should explore, as presented in Ethier (1979a), the reasons behind those returns. IRS emerge conventionally from fixed costs in production linked to learning by doing. Any activity requires an initial investment of time and resources, but as more units get produced, the benefit of the knowledge/resources invested get repaid in full. This conventional view is the basis of the famous works by Krugman (1980, 1981) which stress the role of variety gains from trade in intra-industry trade. This explanation is complementary to the Lancaster (1980) view on product differentiation and the seminal work by Dixit and Stiglitz (1977) on monopolistic competition.

This first segment in the literature provided an elegant rationale for intra-industry trade in

consumption goods and still is the source of numerous articles. A second explanation for IRS is explored by Ethier (1979a), born from the international division of labour. Going back to Smith, Ethier shows that the logic of the division of labour behind the pin manufacture in a cost-free world (both in assembly and transportation) should not be limited to the domestic economy. Ever increasing division of labour segments the production process with increased specialisation of the sub-components and helps productivity improvements, creating on the way new products. One may consider an example of spare parts such as car seats which used to be assembled with cars in the same factory and are now the main product of independent firms. Ethier draws a clear difference between those economies of scale that depend on the size of the world market (bigger countries have more opportunities to segment production processes) and domestic, “plant-size” economies brought by agglomeration forces and product differentiation.

IRS described by both explanations will generate gains from trade. As assumptions differ, so will the nature of those gains. As we saw in the previous chapter, the nature of the gains can make an important difference from a sustainability perspective. Gains from trade arising from variety and learning by doing are quite similar to the Ricardian gains from trade, in the sense that they emerge from domestic characteristics, not directly from interdependence. As such (and as presented in chapter 2), they are either already taken into account by current sustainability theory and measures, or should be considered a bonus demanding no amendments.

Gains emerging from the international division of labour are different in nature. They provide an explanation for the observed intra-industry trade in intermediate goods² and for the resulting global supply chain. They impact domestic resource allocation too. Intuitively, realising those gains from trade will require increased interdependence and further integration of the world economy. As such, those gains may demand further amendments to sustainability measures.

The Ethier model is presented through several articles (Ethier 1979a,b, 1982) and describes the impact of IRS based on the division of labour on international trade theory. Puzzled, Ethier notes in those articles that the IRS he studies seem to warrant little interest. He thought at the time this could be explained by the conjunction of theoretical difficulties in establishing the framework, the existence of other more seducing explanations and the youth of the empirical evidence.

Thirty years later, the model is now well-known, but still gets less credit than it deserves (in our humble opinion). We strongly believe that the need for a sustainability theory should elicit renewed interest in the model. To our knowledge, it is still the most relevant to the analysis we

2. Which is a broader aggregate including intra-firm trade, similar in rationale and impact in the theoretical model we use.

are about to conduct. In chapter 3 we presented extensively the dynamics of our Heckscher-Ohlin model. In this chapter, we focus on comparative statics. This method is sufficient enough to study how IRS will impact the conclusions reached in the previous chapter, notably those on the consequences for Adjusted Net Savings.

I.1 The final goods model and the allocation curve

The first part of the Ethier model is presented in the 1979a article. The problem with the construction of a theoretical model incorporating IRS is that IRS tend to generate multiple equilibria, which in turns introduce arbitrary picking within those equilibria for comparison purposes. Ethier introduces a simple solution to solve this. By summarising the standard technology on which factor allocation is based into one function, the model guarantees the uniqueness of the equilibrium. Another concern emerges from the impossibility to use marginal pricing. Ethier uses the assumption of free entry to justify the fact that firms will stick to average pricing. The possibility of new competition if prices rise above this level is assumed to be deterring enough.

Hence, even if the equilibria in the model are not Pareto-optimal, they are unique and stable. Those sensitive issues out of the way, IRS help to bring the concerns regarding relative size in the equation. The central theme of the model is the interdependence of world industrial activity, although this first part mostly deals with the consequences for usual inter-industry trade. The world economy is composed of 2 countries exchanging manufactures (M) and wheat (W). Economies are dissimilar in factor endowments.

Manufactures are produced using produced capital K and wheat using natural capital N . The domestic country is assumed to be produced capital intensive and the foreign country is natural capital intensive. The production of manufactures is subject to IRS. Domestic scale of manufacturing is represented by the parameter m . m is obtained via the concave production possibility frontier presenting the relation between wheat and manufactures. This production function is neoclassical, of the Heckscher-Ohlin type:

$$m = T(W) \tag{4.1}$$

$$m^* = S(W^*) \tag{4.2}$$

* indicates the foreign country. As manufacturing is characterised by IRS, the extent of

economies of scale is given by the parameter k , defined as:

$$k \equiv \frac{M}{m} \quad (4.3)$$

$$k^* \equiv \frac{M^*}{m^*} \quad (4.4)$$

As was made clear above, k and k^* depend on world production and on the development of manufacturing in both countries. Assuming a world increase of 1% in $m + m^*$ raises $M + M^*$ by $\alpha\%$, free-trade implies that:

$$k^* = k = (m + m^*)^{\alpha-1} \quad (4.5)$$

With $\alpha > 1$ ³. To solve the problem of multiple equilibria, Ethier further assumes $T' < S'$ for a given point where average output between countries is equal. This is equivalent to assuming relative intensity in produced capital in the home country under an HO structure⁴. Finally, Ethier assumes that the world always spends a constant proportion of income γ on manufactures to set the demand function.

Ethier then interrogates the efficiency of output, understood as both countries output being on the production frontier. He notes that this is equivalent to maximising $m + m^*$ constrained by maximising feasible output of wheat $W + W^*$. As α is a constant, optimal allocation does not depend on the magnitude of economies of scale. This leads to proposition 1:

P1: Internationally increasing returns to scale have no effect upon the efficient patterns of production

The shapes of $T(W)$ and $S(W^*)$ will determine the efficient allocation. Ethier is keen to stress that the proposition merely underlines what should happen for production efficiency, and this is only a matter of allocation between manufactures and wheat. It is highly relevant to our point to present the example he uses to show the consequences on output.

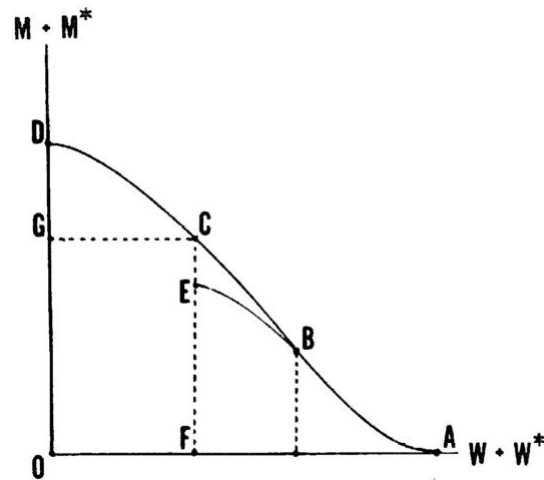
Consider the following home production possibility, where manufactures are expressed as a function of wheat:

$$M = kT(W) = [T(W) + m^*]^{\alpha-1}T(W) \quad (4.6)$$

3. As noted in Ethier (1979a) an important simplifying assumption to this result is that k and k^* have identical definitions. k and k^* do not depend alone on m and m^* respectively, that is the starting point from CRS.

4. As stated by the author, this also means than under CRS domestic country has a comparative advantage in manufactures, in line with the Heckscher-Ohlin theorem.

Figure 4.1: Production shares with IRS



Source: *Ethier (1979a)*

This function is reduced to $M = T(W)^\alpha$ if foreign manufacturing does not contribute to domestic production. Otherwise, it becomes meaningless to talk about a domestic production frontier as domestic production depends on foreign production. Only the world level production set can be considered. Let us consider figure 4.1 showing the world production frontier, the curve ABCD. Under the assumption that domestic country is produced-capital intensive, the foreign country specialises in wheat and the domestic country produces both goods along AB.

Between B and C both country produce both goods, and between D and C home specialises in manufactures while foreign country produces both goods. The domestic production bloc is FABE, and the world production frontier is above, between B and C because the foreign country shifts the domestic production possibilities as it starts producing manufactures itself. Hence, both the IRS effect and the shift in production patterns are at play between B and C.

An interesting case echoing our concerns regarding FPE is the case where T is everywhere steeper than S . In that case, complete specialisation happens as it makes sense to centralise the production of manufactures in the home country (since again T is everywhere steeper). This does not mean that the production of intermediates should be concentrated in the home country. Still, in that setting $B = C$ and when reaching B from A, the production frontier jumps straight to a level equivalent to D. In this example, the patterns of production of the goods we observed in chapter 3 are still observable.

A breakdown in FPE linked to high asymmetry in factor endowments creates complete specialisation, and a jump from one equilibrium where one country specialises to the equilibrium where the other country specialises. In line with proposition 1 we see that the *pattern* of

production is determined solely by the shape (steepness) of the home and foreign production function, but that the *level* of output integrates the contribution of IRS. This property of international economies of scale is fundamental to our conclusion.

The second important contribution of Ethier (1979a) is the technique of the allocation curve. To present it, we must briefly outline the challenges laid by finding the free-trade equilibrium with IRS. In autarky, international IRS and national IRS are by definition the same. Let P_D^H be the home relative demand price of wheat in terms of manufactures. This is the price that will equate demand and supply for any level of W and corresponding M . With IRS, average cost pricing is applied, disciplined by free entry. Based on the assumption regarding the demand function:

$$P_D^H = \frac{(1-\gamma)T(W)^\alpha}{\gamma W} \quad (4.7)$$

Sensibly, the relative price is the ratio of the demand addressed to the manufacturing sector (where production is in autarky without economies of scale) over the demand addressed to the wheat sector. The home relative supply price pins down the production equilibrium in terms of W and M :

$$P_S^H = -kT' \quad (4.8)$$

$$P_S^H = -T(W)^{\alpha-1}T'(W) \quad (4.9)$$

The intersection of the two curves gives the equilibrium price:

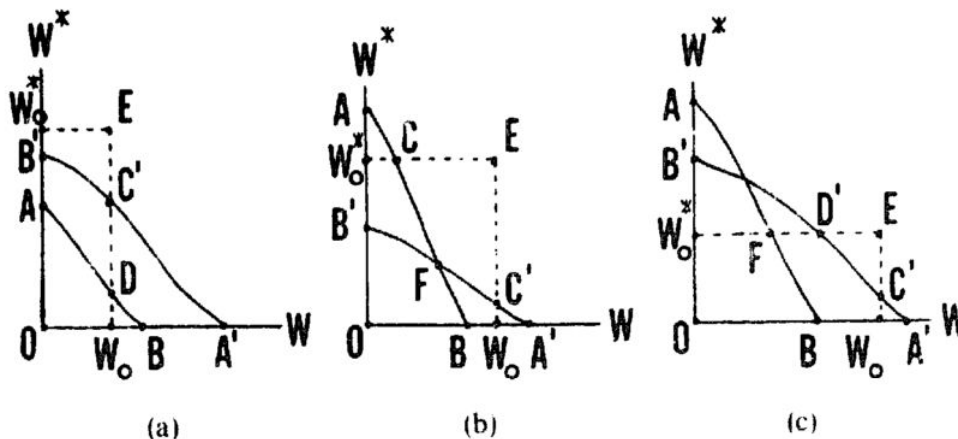
$$P^H = -T(W')^{\alpha-1}T'(W') \quad (4.10)$$

With the corresponding equilibrium value for W which solves $-T'(W) = \frac{(1-\gamma)T(W)}{\gamma W}$. As the demand prices curve is cut from below by the supply prices curve, the equilibrium price and quantities are stable. Output increases for as long as the demand price is superior to the supply price and vice-versa. In line with the literature on domestic returns to scale, it is clear from 4.10 that the equilibrium price depends positively on the scale variable $T(W)$. The larger the country, the bigger the domestic economies of scale and the higher the autarky price.

We are now facing a problem. Proposition 1 states that the comparative advantage will be determined under IRS as with CRS due to the fact that production patterns are the same. Defining comparative advantage with respect to autarky prices leads us to believe it depends on domestic economies of scale of the traditional fashion.

To solve this elegantly, Ethier (1979a) suggests the allocation curves technique. Consider

Figure 4.2: International trade equilibria and allocation curves



Source: Ethier (1979a)

figure 4.2, where three W/W^* diagrams are drawn. The scale of manufactures production can be deduced from 4.1 and 4.2. The domestic curve AB links a given level W produced domestically to the foreign level W^* that will allow for equilibrium in the domestic economy. For a given level of wheat output $W + W^*$ and the related manufactures production $[T(W) + S(W)^*]^\alpha$, the resulting world demand price sets the combination (W, W^*) on an allocation curve if world markets are cleared with $P_D = P_S^H$.

Hence, on the allocation curve $P_D = P_S^H$ it follows logically that $P_D < P_S^H$ is above the allocation curve and $P_D > P_S^H$ is below respectively. Points E in each panel represents the maximum reachable level of domestic wheat production, so that $(W_0^*, E, W_0, 0)$ rectangles are production sets. The domestic allocation curve is given by the lowest segment inside the rectangle, so that it is $W_0^*ADW_0$ in diagram (a), CB in diagram (b) and FB in diagram (c).

The international equilibrium is given by the intersection of the two allocation curves. As in the example above, the nature of the intersection gives the specialisation patterns for countries. In sub-figure (b) both countries diversify, as $W \neq W^* \neq 0$. As there is an interior solution, $P_S^H = P_S^F$ in equilibrium, and $T' = S'$. As in the example above, if T is everywhere steeper because of high asymmetry in endowments, then there is no intersection. Remember that since the domestic country is more produced capital intensive, T is steeper than S , which guarantees uniqueness of equilibrium.

In the high-asymmetry case, T is everywhere steeper, which (as factor price equalisation breaks down) leads to complete specialisation. In (a) the domestic country completely specialises in manufactures and in (c), the foreign country specialises into wheat. From this

demonstration Ethier concludes that the patterns of production are in line with proposition 1, vindicating it as the rule to identify comparative advantages against autarky prices. Regardless of the size of the country and the domestic economies of scale, the equilibrium pattern under international trade will reflect the CRS pattern.

The reader is referred to the remainder of the article for a more in depth formal demonstration and the exploration of the case where T' and S' are constant. We shall now turn to the intermediate goods trade, happening in the background of the trade in final goods described until this point. Trade in intermediate goods is important as it is the source of the IRS motivating the article. To fully explore this aspect, we start with the proposition 6 from the 1982 article. We continue with the discussion on the trade of intermediate goods.

P6: Internationally decreasing costs imply a presumption that a greater similarity of $T(W)$ and $S(W)^$ results in a larger volume of trade in intermediate manufactured goods, both absolutely and relatively to the volume of inter-industry trade.*

Large differences in $T(W)$ and $S(W)$ get the foreign country to specialise, leading to the exchange of wheat against all the intermediate components of manufactures, that is pure inter-industry trade. Conversely, if endowments are similar, then incentives for inter-industry trade disappear while intra-industry trade rises boosted by growing production of manufactures in both countries. In the limiting case where $S = T$ international trade consists only of intra-industry trade. The larger the international scale economies k , the bigger the effect. There is therefore substitution of intra-industry trade for inter-industry trade as asymmetry in endowments decreases. This result, now quite standard in trade theory, will be discussed after the presentation of the 1982 extension of the model.

I.2 The intermediate goods model

The second part of the Ethier model in the 1982 article is dedicated to the analysis of trade in intermediates. It follows naturally from the conceptual framework presented above in the 1979a article. The main aim of the article is to investigate the consequences of IRS on the main theorems of neoclassical trade theory. Following the first part of the model, Ethier concludes that intra-industry trade, just like inter-industry trade is factor endowments based. Ethier demonstrates this by adopting an explicit production structure for the intermediates.

Produced capital K and natural capital N are combined to produce two goods, wheat W and manufactures M . W is subject to CRS via a smooth production function (satisfying

the Inada conditions). Manufactures are subject to IRS, under a separable function $M = km$ where k is an index of scale economies and m an index of the scale of operations. Those are the familiar domestic and international scaling parameters from the previous section. m is produced with the same smooth production function. This production function can be summarized by a transformation curve:

$$W = T(m) \tag{4.11}$$

$T(m)$ is the usual H-O model production set. The transformation curve represents any convex production set, but Ethier assumes that the implicit structure is HO. Factors are combined following the simple reference model from Findlay (1995). In this static model, the supply of K and N are fixed:

$$X = X(K_x, L_x) \tag{4.12}$$

$$Y = Y(K_y, L_y) \tag{4.13}$$

$$K_x + K_y = \bar{K} \tag{4.14}$$

$$L_x + L_y = \bar{L} \tag{4.15}$$

Production functions, CRS, in per unit of labor form:

$$x = x(k_x), x'(k_x) > 0, x''(k_x) < 0 \tag{4.16}$$

$$y = y(k_y), y'(k_y) > 0, y''(k_y) < 0 \tag{4.17}$$

If Y is the numeraire and denoting the relative price of X as p

$$px'(k_x) = y'(k_y) = r, \tag{4.18}$$

$$p[x(k_x) - x'(k_x)k_x] = [y(k_y) - y'(k_y)k_y] = w \tag{4.19}$$

Finished manufactures are costlessly assembled from intermediates (or components). All intermediates are assumed to be producible using the two factors mentioned above. There are n intermediates, which number is endogenously determined. All intermediates enter the production of manufactures in the same way. The amount of a given component produced is noted x_i . Once a component is produced, it will be produced in the same amount as the other produced components. Total production is therefore nx . The output of manufactures M is by assumption given by the function:

$$M = n^{\alpha-1}(nx) \tag{4.20}$$

For $\alpha > 1$. This is in fact the special case for $x_i = x$ of the more general production function:

$$M = n^\alpha \left[\sum_{i=1}^n \left(\frac{x_i^\beta}{n} \right) \right]^{\frac{1}{\beta}} \quad (4.21)$$

Higher β indicates a higher degree of substitution between components. Conversely, lower values for β reflect differentiation in intermediates. Taking a somewhat different interpretation for the variable m , Ethier considers it as an index of the number of bundles of factors devoted to manufacturing production. The values for the bundle are computed below:

$$m = n(ax + b) \quad (4.22)$$

With $a, b > 0$. We find with this definition the same domestic economies of scale, motivated by a fixed cost b which generates plant size IRS. Those are assumed internalised by firms in this model. The total output of one component is produced by one firm in one location nationally to internalise those IRS and differentiate it from the international variety. Those economies of scale in turn come from n . Equation 4.20 displays CRS for a given value of n , but a rise in n with constant x creates IRS, since M rises by more than nx thanks to the $\alpha - 1$ power and $\alpha > 1$ assumption. Those economies are related to the size of the market: a bigger market gives scope to the production of more components, as was the case in the previous section.

The autarky equilibrium can be obtained from those equations. Individual producers of manufactures takes n as given. Consider q_0 and q the price in terms of wheat of two components with corresponding outputs x_0 and x . Cost minimization subject to equation 4.21 yields:

$$x_0 = x \left(\frac{q}{q_0} \right)^{\frac{1}{1-\beta}} \quad (4.23)$$

With n large, each producer's behaviour has no influence on the others so that equation 4.23 is the demand curve faced by any given producer of components, as a function of any other producer's price and quantity. Factors are purchased competitively, so that the cost function for component producers is $-T'(m)[ax_0 + b]$, a familiar form. Equating marginal cost with marginal revenue under profit maximisation gives the price:

$$q_0 = -T' \left(m \frac{\alpha}{\beta} \right) \quad (4.24)$$

This expression holds for every component produced because of the symmetry assumption. Total profits for component producers are $q_0 x_0 + T'(m)[ax_0 + b]$, drawn to zero by firm entry,

i.e. changes in n . Therefore, quantities produced when profits are null are:

$$x_0 = \frac{b\beta}{a(1-\beta)} \tag{4.25}$$

Substituting into 4.22, conditional to a given technology m and as in equilibrium $x = x_0$, we obtain the number of components producers:

$$n = \frac{(1-\beta)m}{b} \tag{4.26}$$

and the value of k , representing the international economies of scale for the manufacturing sector:

$$k = \left[\left(\frac{1-\beta}{b}\right)^{\alpha-1} \frac{\beta}{\alpha}\right] m^{\alpha-1} \tag{4.27}$$

From there, we can draw the supply and demand curves for manufactures. The relative supply price in terms of wheat P_S is shown to be $P_S = \frac{-T'(m)}{k}$, which is the supply curve for manufactures. The transformation curve term m is not related to x , so that a reallocation of factors via the m term from the production of W to M will not increase output x , but will via equation 4.22 increase the number of components producers. There are therefore IRS in the manufacturing sector and the supply curve of manufactures is downward slopping.

As for the demand curve, Ethier uses again the assumption that a constant share γ is spent on manufactures, which yields the following demand curve:

$$P_D = \left[\frac{\gamma}{(1-\gamma)}\right] \frac{T(m)}{km} \tag{4.28}$$

With P_D the relative demand price for manufactures in terms of wheat. The demand curve intersects the supply curve from above, guaranteeing uniqueness and stability as in the 1979a article.

The international equilibrium can be obtained from there, using the allocation curves technique. The difference between countries comes from differences in factor endowments, with m and m^* the scale of manufacturing operations. * indicates again foreign country variables. If m and m^* are both positive, the whole production of a given component is in one country so that the two countries produce two different subsets of components. Under free-trade, the world works as an the integrated economy so that from equations 4.25 and 4.26 we can write:

$$n_H = \frac{(1-\beta)m}{b} n_F = \frac{(1-\beta)m^*}{b} n = \frac{(1-\beta)(m+m^*)}{b} \tag{4.29}$$

With n_H the number of components produced in the home country and n_F the number produced in the foreign country. From equation 4.20 in equilibrium it follows that total manufacturing production is:

$$M + M^* = \left(\frac{\beta}{\alpha}\right) \left[\frac{(1-\beta)}{b}\right]^{\alpha-1} (m + m^*)^\alpha \quad (4.30)$$

Similarly, the demand curve is transformed into:

$$P_D = \frac{\gamma}{1-\gamma} \frac{T(m) + S(m^*)}{M + M^*} \quad (4.31)$$

Which yields after substitution:

$$P_D = \frac{\gamma}{1-\gamma} \frac{a}{\beta} \left(\frac{b}{1-\beta}\right)^{\alpha-1} \frac{T(m) + S(m^*)}{(m + m^*)^\alpha} \quad (4.32)$$

Where $S(m^*)$ is the foreign transformation curve. The home supply price is then given by:

$$P_S^H = - \left[\frac{(1-\beta)(m + m^*)}{b}\right]^{1-\alpha} \frac{T'(m)a}{\beta} \quad (4.33)$$

Equilibrium in the manufactures markets in the domestic country requires $P_D = P_S^H$, which yields:

$$\gamma[T(m) + S(m^*)] + (1-\gamma)(m + m^*)T'(m) = 0 \quad (4.34)$$

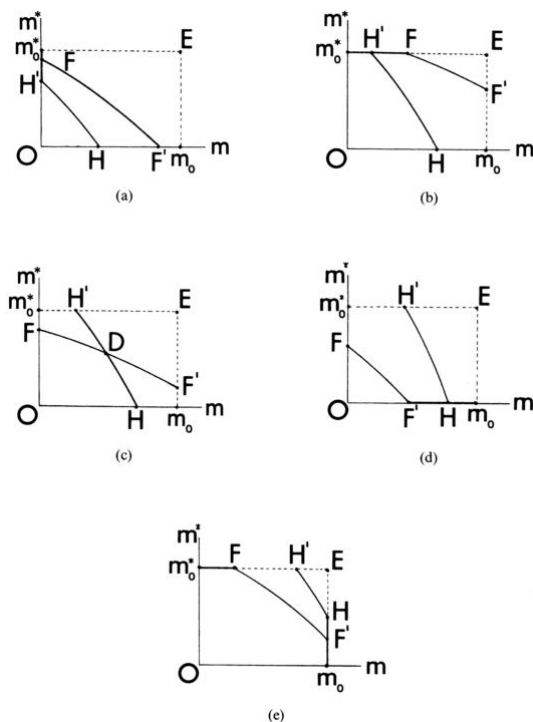
The domestic allocation curve depends on the combinations of m and m^* . Correspondingly, the foreign allocation curve is given by:

$$\gamma[T(m) + S(m^*)] + (1-\gamma)(m + m^*)S'(m) = 0 \quad (4.35)$$

The two allocation curves are represented in (m, m^*) diagrams, in figure 4.3. The domestic allocation curve is represented by the (H', H) curve and the foreign one by the (F', F) curve. The greatest extend possible for production is represented by the square $(m_0^*, E, m_0, 0)$. The domestic allocation curve should be completed by the segments $[H', m_0^*]$ and $[H, m_0]$ when existent, and the foreign one by the segments $[F, m_0^*]$ and $[F', m_0]$.

Hence, the equilibria at the intersection of the two curves in each panel are F, H', D, H, F' for panels (a) to (e). Panels (a), (b), (d) and (e) depict the scenarios where complete specialisation occurs. In panel (a) for instance, the equilibrium in F implies complete specialisation in W for the domestic country while foreign does not specialise and panel (d) implies complete specialisation in wheat for the foreign country while domestic country does not specialise.

Figure 4.3: Allocation curves and world equilibria



Source: Ethier (1982)

The shape of the allocation curve is determined by the shape of the transformation curve, since by the separability assumption one can write $M + M^* = k(m + m^*)$ where depends only on b, β, α, m and m^* . The total production of components is distributed across countries following the calculated values for n_H and n_F once x is calculated. Without explicit assumption on assembly, the total production $M + M^*$ can be split in any fashion. This means that M and M^* do not necessarily reflect the quantities produced respectively in domestic and foreign countries.

A final note on the equilibrium should be made. With this explicit production structure for the intermediates/components generating the international economies of scale, the proposition 1 of the 1979a article remains valid. Factor allocation is still solely determined by the transformation curves $T(m)$ and $S(m)$. The model having more traded intermediate goods than factors still yield indeterminacy in the actual production of manufactures, although the production of components is fully determined by n and x . Hence, those values for n and x depend on the equilibrium which in turns depends on the transformation curve and respective factor endowments. The presentation of the adapted version of the canonical theorems will help us understanding the impact of this trade in intermediates.

Starting with the assumption that countries are in the panel (c) situation, where both

are diversified. This implies that at the intersection point $T'(m) = S'(m)$. With identical technology, this implies that components are priced evenly across countries. Therefore, in the scenario where both country diversify, factor price equalisation holds. It breaks down when the shape of allocation curves (via high-asymmetry in endowments) pushes the equilibrium to the other cases in panel (a), (b), (d) and (e).

The Rybczynski theorems demands greater alterations. Equilibrium equations shows that changes in endowments do not affect the output x of components but the number n of components producers will change in proportion to m . This gives proposition 2:

P2: Rybczynski. At constant relative component prices, an increase in the produced capital stock will absolutely reduce the production of wheat, have no effect on the outputs of all components initially produced and increase the number of produced components in greater proportion than the rise in the produced capital stock itself.

The change here is introduced at the intra-industry level, not the inter-industry level which is unaltered. The change in m will be magnified by the scale effect introduced by k (and through it by the extend of internal economies of scale α). Total change is the proportional change in m times the scale effect in k . Therefore, economies of scale only accentuate the standard results. The price of components being kept constant, there is still a relative increase in manufactures output with respect to components (and to the produced capital stock) while the price of manufactures fall.

We briefly note that the quantity version of the Heckscher-Ohlin theorem remains intact, while the price version requires an alteration. This alteration demands the consideration of the case where intra-industry-trade happens to allow for economies of scale but inter-industry trade is forbidden ("quasi-autarky"). The "quasi-autarkic" amendment is mostly relevant to trade between similar countries when intra-industry trade dominates although this scenario is not relevant to our problem.

Modifying the Stolper-Samuelson prediction requires to come to grasp with a critical answer to our problem: the impact of trade in components on factor prices. Understanding this impact requires relationships between the price of components and the price of final goods. This is obtained via the definition of the *inter-sectoral price effect* and the *scale effect*. The inter-sectoral price effect comes from the fact that if factors move from the wheat to the manufactures sector, it will increase the price of components relative to wheat in line with the transformation curve.

This will also raise the price of manufactures compared to the price of wheat. The scale effect is the consequence of the variation in n implied by any allocation. More resources devoted to manufacturing will reduce the relative price of manufactures via the international economies of scale, going against the inter-sectoral price effect. This gives proposition 5:

P5: *If the scale effect dominates the inter-sectoral effect, changes in the intra-sectoral price structure $\frac{P_M}{P_C}$ are magnifications of the changes in the intersectoral structure $\frac{P_M}{P_W}$. If the inter-sectoral effect dominates the scale effect, the two relative prices always change in opposite directions.*

An increase in the price of manufactures raises the rent from produced capital and lowers the rent from natural resources if and only if the inter-sectoral effect dominates the scale effect. If the scale effect dominates, then the opposite is true.

Finally, Ethier (1982) presents the most critical contribution to our topic, the factor-endowments basis of intra-industry trade. The conclusion of the section was already apparent in the first part of the model in the 1979a article. Ethier assumes from here that finished manufactures are assembled costlessly in the consumption country, with each component entering in the production function only once. He then presents the Grubel-Lloyd 1975 index defined as:

$$\rho = 1 - \frac{|X_C - M_C|}{X_C + M_C} \quad (4.36)$$

With ρ the Grubel-Lloyd index, and C indicating the domestic country. The Grubel-Lloyd (GL) index is a measure of intra-industry trade: if $\rho = 1$ trade is only intra-industry in manufacturing and if $\rho = 0$ trade is only inter-industry. The application of the GL index to the definition of imports and exports in the model yields the complementarity theorem:

P11: *Complementarity Theorem. If both countries initially produce both goods, and if there are no separating factor-intensity reversals, a small relative-endowment-equalizing will increase ρ .*

So that the movement from high to low asymmetry will effectively increase the volume of intra-industry trade in total trade with international economies of scale. Inter and intra-industry trade are in fact complementary in terms of asymmetry in endowments. The fundamental role of factor endowments is further reinforced by proposition 12 which states that the technological parameters a, b and β have no impact on the prevalence of intra-industry trade (that is the value of ρ). A notable result is that higher product differentiation, defined by β , reduces in similar

amount inter and intra-industry trade. Higher product differentiation increases the number of components but reduces output by a larger extent because of fixed costs.

This concludes our presentation of the Ethier model, presented in the 1979a and 1982 article. The model provides a useful and robust background to assess the impact of international economies of scale, as opposed to usual, domestic economies of scale generated by learning-by-doing and/or fixed costs.

In the next section we confront the conclusions of the Ethier model to our conclusions from chapter 3. We then discuss the implications for sustainability.

I.3 Discussion of the section: consequences for ANS

In this section we address the two questions raised by international economies of scale for sustainability:

- Do international economies of scale have an impact on development paths and resulting interindustrial trade flows?
- Does inter-industry trade emerging from international economies of scale warrants additional savings?

Those two questions can be answered on the basis of the propositions presented in the Ethier model. We should first summarize briefly the pattern of trade derived from our model in chapter 3. In this model, both countries trade goods that are intermediates used to produce a final good which is non-traded. Those goods are effectively produced with constant returns to scale technologies, used in the production of the final good which is also produced with constant returns to scale. This structure requires that when opening-up to trade, countries de facto allocate endowments between the intermediate sectors.

Those intermediates goods are created in order to take advantage of each country's comparative advantage, as those intermediates are relatively intensive in one factor. This is the source of trade flows in a dynamic HO framework. Although the traded goods in the model are intermediates with respect to the final good, they are in fact traded on an inter-industry basis. They use different factors and can reasonably be assumed to be different in nature as they are all required for the production of the final good.

Another important feature of the model is the parameter α which is the parameter allocating resources in the final good Cobb-Douglas function. The parameter defines the repartition of

resources between the intermediates intensive in one given factor, and the intermediates using all factors in equal proportions. We showed at the end of the previous chapter that our conclusion regarding free-trade and autarky did not depend on the value of this parameter. This means that even in a setting where both countries only produce the four intermediates generating a comparative advantage, consumption and wealth are lower under free-trade compared to autarky.

The economic intuition behind this result is the added organisational complexity induced by free-trade and setting production to be exported and imported. Still, we showed that the reallocation of resources between autarky and free-trade lowered production but resulted in lower prices. Crucial to sustainability, convergence from high to low asymmetry under free-trade is performed with a lower increased in the price of factor which becomes scarcer in the process (natural capital in type two countries) and a more pronounced decrease in the price of factor becoming more abundant (such as produced capital and labour in country-two type countries).

We concluded that this spread between autarky and free-trade prices multiplied by the amount of factor endowments effectively mobilised in the production process in the considered period should be saved and reinvested. Indeed, those gains from trade are generated by a deviation in the accumulation path of factors compared to autarky. Therefore, in a logic akin to capital gains those resources should be levied to finance reinvestment and structural change as they would have been invested under autarky, in line with domestic preferences.

This result rests critically on factor endowments, so that the first modification we should eventually implement faced with IRS would be motivated by the impact of IRS on factor endowments. The second element critical to this definition is the price system. If IRS impact factor prices, then the savings rule must be modified accordingly. Third, the expected volume of exchanges in free-trade when in autarky does not matter, in the sense that both the technology and the α parameters have no impact on the conclusion.

A first important conclusion of the model is the stability of equilibria with international economies of scale. Decreasing costs of production do not imply indeterminacy, as long as one production space results in a steeper allocation curve, which is the case under HO technology. As equilibrium selection is not arbitrary, the results of the Ethier model can be applied to other context where equilibrium is also unique, that is derived from a given pattern of specialisation. This being clearly stated, the answer to question one can be drawn from the final goods version of the model.

Proposition 1 in the 1979a article clearly states that even if intermediates are produced with IRS, the allocation of factor endowments is determined by the transformation curve which follows CRS HO technology. This result holds even in the scenarios where FPE breaks down and one country specialises completely. This does not mean that the volume or the final output would be the same, but the allocation of factors will be. This is a critical result as it gives a way out of the somewhat puzzling conclusions that free-trade leaves country worse-off than autarky.

IRS provide countries with an incentive to open-up to trade, to benefit from increasing returns to scale in sectors where production technology allows for increasing international division of labour. This incentive can be obtained with the same pattern of factor accumulation, or degree of asymmetry, as gains from IRS are independent. Our model in chapter 3 should be modified to exhibit this effect in full, but the general sense of the results can be deduced from the Ethier model.

Answering our two opening questions requires to turn to the Stolper-Samuelson theorem amended in proposition 6 of the 1982 and the inter-sectoral effect versus the scale effect. The inter-sectoral effect is the effect at play in the regular HO version of the Stolper-Samuelson theorem. If it dominates, an increase in the relative price of manufactures produces a more than proportional change in the relative price of components. If the scale effect dominates, the relative price of components will go in the opposite direction.

The introduction of IRS disturbs the response of factor prices in the sector affected by IRS, the intra-industry price structure between manufactures and components. This means that the gains emerging in sectors not directly affected by IRS, (in the Ethier model the wheat sector) will be unaffected. The proportional change induced by modifications in the price of wheat is the same, while the combination of factors is also unaffected. Disturbance will come from the manufacturing sector, where an increase in the price of manufactures relative to wheat raises return on produced capital and lowers return on natural capital relative to both final good prices. This is the case in which the inter-sectoral effect dominates the scale effect (the change is more than proportional). This means that international economies of scale will suppress some of the rise in natural capital return and magnify the increase in produced capital return if the inter-sectoral effect dominates in the context of higher world demand for manufactures.

If the scale effect dominates, the conclusions are less clear and depend on the allocation of resources between the sectors. Differences between the Ethier model and our model in chapter 3 prevent us from drawing a clear conclusion. The best that can be said from intuition is that a larger scale effect is likely to lower the return on produced capital, the effect on natural capital return depending on technology and resource allocation and the size of the scale effect

relative to the inter-sectoral effect. This somewhat imperfect conclusion leaves us with the certainty that international economies of scale will affect the evolution of the return of the factor the sector concerned with those IRS is relatively well-endowed with. This is true even if the underlying level of asymmetry in endowments is unchanged.

Doing so, IRS creates the need to amend the measure of the gains from trade presented in chapter 3. If the inter-sectoral effect dominates, IRS will have reduced return on natural capital, making it cheaper to use relative to autarky for a given level of asymmetry. IRS will conversely make produced capital more costly, although this goes with increased output and consumption. IRS distort the goods price system and via the Stolper-Samuelson theorem, requiring in this case more savings than under the CRS case.

This point is critical when moving from comparative statics to dynamics. IRS distort the price system leaving factor allocation between the two sectors untouched, so that *a priori*, as only relative prices are altered then only the measures of gains from trade using those prices should be corrected. The “physical”, capital stock dimension is unchanged. Yet, in a dynamic perspective, this distorted price system will change the investment incentives in the next period, altering the physical reality this time.

We need to consider two price systems. The first one is the price system resulting from production under CRS, the second one is under IRS. Then we need to consider the changes brought by the dynamics into the savings rule. In comparative statics it looks as if the distortion generated by the IRS price system simply requires saving under the IRS price system to take place *as if* under the CRS price system. The resulting difference in savings being effectively freed to be consumed⁵. So that in comparative statics, savings ought to be *lower* than could be deduced from the IRS price system.

In a dynamic perspective, those distorted prices get built in into the investment decisions, and encourage in our example over depletion of “cheap” natural resources to invest in relatively more expensive produced capital. Therefore, the difference now has to be added in full to savings and not consumed, since the beginning of the period prices come from the IRS price system and not from the counterfactual “CRS” system. This brings us to a paradoxical situation. International economies of scale do not distort allocation of resources between sectors, so that the allocation resulting from inter-industry trade is valid, even when one of the goods traded is produced from components under IRS.

5. This difference is always positive under the result that if the inter-sectoral effect dominates, the IRS price system introduces larger than proportional changes.

Changes in the goods prices structure impact the factor prices structure. Although they will not change the allocation structure in the current period, they will do so in the forthcoming period, demanding ex-post extra resources. This creates a dilemma. Countries have the choice between on the one hand saving as in under CRS and in line with the observed allocation but then following short in terms of savings in the next period. On the other hand they can save according to the observed IRS hence “over-saving” from the perspective of the actual allocation of factors that still obeys the CRS allocation.

This dilemma should not surprise us if we note the problem faced by Ethier (1979a) where the comparative advantage could either be estimated using autarky prices or production efficiency. The paradox we face here have similar roots. Ethier warned that the price system in his model, although producing stable equilibria, will not be Pareto-Optimal. However, when Ethier could arbitrage against autarky prices, we cannot do so as the price system in a dynamic setting is the marker of intergenerational equity.

This remark together with the precautionary principle should warrant the country, facing this paradox, to save more (that is following the observed price system). The other, non-normative way to solve the paradox is to acknowledge, as is often the case in the environment literature, that IRS make market prices deviate from shadow prices. Therefore, investment should be conducted ignoring those market prices and following the efficient (in our case CRS) price system. Although more theoretically compelling, this solution raises several practical issues, the least implying the difficulty to estimate a parallel system of shadow prices. Again, our demonstration describes the case where the inter-sectoral effect dominates the scale effect. If the scale effect dominates, other factor needs to be considers.

It would be idle to consider the case where the scale effect dominates without a formal model, as a way to measure the forces at play here. Let us mention though that in this scenario, the volume of trade is likely to play a role. We know from proposition 12 in the 1982 article that an increase in product differentiation, will decrease both inter- and intra-industry trade. Even if the number of components produced increases, the output of each component producers falls more than proportionality.

Let us assume that as in our model in chapter 3 the volume of trade increases exogenously (translating into an increase in the value of α). This increase is neutral in terms of endowment structure under CRS. Under IRS if the inter-sectoral effect dominates, this effect is equivalent to a price increase in manufacturing presented above. If the scale effect dominates (strongly) the return on natural capital should rise and the return on produced capital should fall, relative to the CRS levels. An overall increase in the volume of trade then yields the expected impact of IRS, making the factor the country is relatively intensive in cheaper and the other factors

relatively more expensive.

This ends our discussion on IRS and savings. We found that IRS are likely to modify inter-industry indirectly in a dynamics context, via the impact of prices on the patterns of factor accumulation. We saw that in this context, additional savings from the gains resulting from trade on intra-industry trade flows are also warranted. This result can be seen as a consequence of the dissociation of market prices and shadow prices. Ethier (1979a) stressed that IRS would bring some interesting economic policy questions, “particularly if the increasing returns are due to economies external to the firm but internal to the international market”. We believe again that the sustainability approach shed some light on those questions. We discussed briefly the impact of exogenous variations in the volume of trade. One of the conclusions, essentially HO, in chapter 3 was the extinction of international trade as endowments grow similar. Proposition 1 in the 1979a article shows that intra-industry trade exists even in cases of complete specialisation. Proposition 11, the complementarity theorem, shows that in the course towards factor endowments equalisation, intra-industry trade increases as inter-industry trade is decreasing.

This now well-known result shows that IRS will prevent the extinction of trade, whether or not the course from high to low asymmetry yields FPE (preventing complete specialisation). Overall, it is also clear that the more one country trades, the more it should save and reinvest. Inter- and intra-industry trade call for different savings rule, but both warrant more savings. IRS clearly reinforce the virtuous circle of reduced asymmetry: higher consumption and higher income leading to more wealth and to more trade that implies reinvestment and endowments asymmetry reduction.

Those conclusions help us discriminating between the likely decisions of countries. Intra-industry trade creates new possibilities of gains, but also new ways to insert the country in the global supply chain. Trade is not merely a way to converge from high to low asymmetry at a lesser cost, but also a way to take part in the international division of labour, even by a small extent. It makes it theoretically possible to be *both* specialised in the sense of the inter-industry trade, and diversified in the sense that some components of several industries can be produced in the country. This is very important for countries characterised by high asymmetry with a long way under structural change. For those countries, opening up to inter-industry trade only is (from chapter 3) not necessarily profitable and creates exposition to factor specific shocks.

IRS and the possibility to enter the global supply chain in a more diversified manner makes it more likely for those countries to enter international trade. In the setting of chapter 3, those would be country 2 type countries in the SC scenario. Country 1 type countries on the other hand clearly have a stronger incentive to trade under IRS, under either low or high

Table 4.1: Possibilities in Multilateral Trade

Case	Endowment	Production	Intraindustry Trade	Interindustry Trade
I	$h \geq h_m$	specialized to m	with all other I, II, III, IV countries	imports W from IV and V
II	$h_m > h \geq h'$	diversified	with all other I, II, III, IV countries	imports some W from IV and V
III	$h = h'$	diversified	with all other I, II, III, IV countries	none
IV	$h' > h > h_W$	diversified	with all other I, II, III, IV countries	exports some W to I and II
V	$h_W \geq h$	specialized to W	none	exports W to I and II

Source: *Ethier (1982)*

asymmetry. The case that is by far the most debatable is the case of country 2 types in CA with low asymmetry. Those countries are very likely to be better-off in autarky even with IRS in one sector. *Ethier (1982)* tried to explore this question by assessing the resulting trade flows depending on factor endowments. We reproduce his synthetic table in figure 4.1.

In the table h_m and h_W denote capital-labour ratios in manufacturing and wheat, and h' is the cut-off ratio. Above this value countries necessarily import wheat and below it countries necessarily export it (assume also $h_m > h' > h_W$). Country two type countries in CA and low asymmetry are in CS, and therefore would be close to case V. The prospect of no intra-industry trade and exports to countries that are either specialised in manufacturing or diversified is not appealing as only CRS production can be expected. This is a corner case and again the concordance of the Ethier model is not perfect, making any direct translation tentative, but this shred of evidence does not point towards free-trade for those countries.

At the very least, those elements reinforce the idea that the case for free-trade depends on the distribution of endowments and on the scenario or “case” that would logically follow. Country two types countries in high asymmetry aiming for the integrated equilibrium in low asymmetry are “stuck” in an exchange pattern that would see them relying heavily on their exports of natural capital-intensive goods (inter-industry trade) and slowly undertaking structural change by substituting endowments and substituting intra-industry trade for inter-industry trade. This is the optimistic dynamic scenario, but it is conditional to a) a sound reinvestment strategy and b) the evolution of trade relations.

One could imagine that if one country undertakes structural change more quickly than its partners, its inter-industry would die down quickly creating a strong asymmetry. It does not need the goods its partners are producing any more, while its partners need to enter intra-

industry trade with this country. This unhappy scenario would see some countries “stuck” in a specialisation and resulting pattern of trade, that it of little interest to anyone else.

Trade is usually assumed to be symmetric, creating interdependence. We see here the possibility of asymmetric interdependence, likely to turn into plain dependence. Interestingly, this possible dependence is based on the difference in the nature of trade, not in the content of trade. Insertion in the global supply chain is optimal because it is the way to get a share of international economies of scale, while being part of the truly interdependent form of trade. Critically these conclusions are independent from the concerns regarding national, plant-size economies of scale and product differentiation. Those questions are related to the size and number of industrial sites and forces of agglomeration. Although they are obviously related, they are beyond the scope of this chapter, as long as countries are still a relevant organisational scale.

The questions we have raised are especially critical in the case of natural capital. Natural capital enters a wide variety of industrial processes, but its exhaustible nature conjugated with property rights issues makes it particularly prone to over-exploitation. There are nonetheless as many possibilities to create a line in the global supply chain for natural capital intensive goods as for any others. The extensive trade in semi-transformed agricultural, mineral and energy products vouches for this. Still, countries with a comparative advantage in natural resources, especially energy resources, seems to be facing relatively more obstacles to development. This phenomenon is known in the literature as the “resource curse” or the “Dutch disease”.

We identified in this section two potential reasons for this phenomenon: a suboptimal investment strategy resulting in delayed structural change, or inconsistent specialisation with respect to trade partners. Note that the two explanations are not mutually exclusive. Hence, the next section is devoted to the discussion on the resource curse.

II Patterns of development and intra-industry trade

Are some countries structurally different, in the sense that mechanisms working in a given fashion in the majority of countries work differently in this considered set of countries? This is the implicit assumption behind the resource curse, the counter-intuitive idea that some countries may witness a decline in economic growth in the wake of natural resources abundance. The aim of this section is not to present an exhaustive survey of the resource curse, subject wide enough to be covered by a whole thesis. Instead, we will focus after a brief introduction on the resource curse, on the trade related explanations for the curse and the Dutch disease. We will

then proceed to an evaluation of the strategy regarding the reinvestment of rents in Russia. The aim of this section is therefore to present the forces affecting reinvestment strategies with a focus on trade motives.

II.1 The Dutch disease and the resource curse: literature review

Discussion on the possibility of a resource curse emerged in the 1990's, but the starting point of the connection between natural resources and economic performance is the Dutch disease. The term was coined after the discovery of extensive natural gas reserves in the north of the Netherlands in the 1960's. According to [Corden \(1984\)](#), the first mention of it can be found in a newspaper article in the Economist, 1977. The basic mechanism can be explained using the model in [Corden and Neary \(1982\)](#) and [Corden \(1984\)](#) based on the original model of [Salter \(1959\)](#). For the sake of conciseness we will use the version of the Salter-Swan model presented in the excellent survey by [Van Der Ploeg \(2011\)](#).

Consider a small two-sector economy with a resource windfall. In this static model we assume balanced trade, so that:

$$H_TQE = C_T - H_TF(L_T) \quad (4.37)$$

With Q the world price for natural resources, E the volume of exports of natural resources, C_T the consumption of traded goods, L_T employment in the traded sector and H_T productivity in the natural resource sector. This makes $H_TF(L_T)$ the output in the traded sector, with F satisfying the Inada conditions. The non traded goods equilibrium is given by:

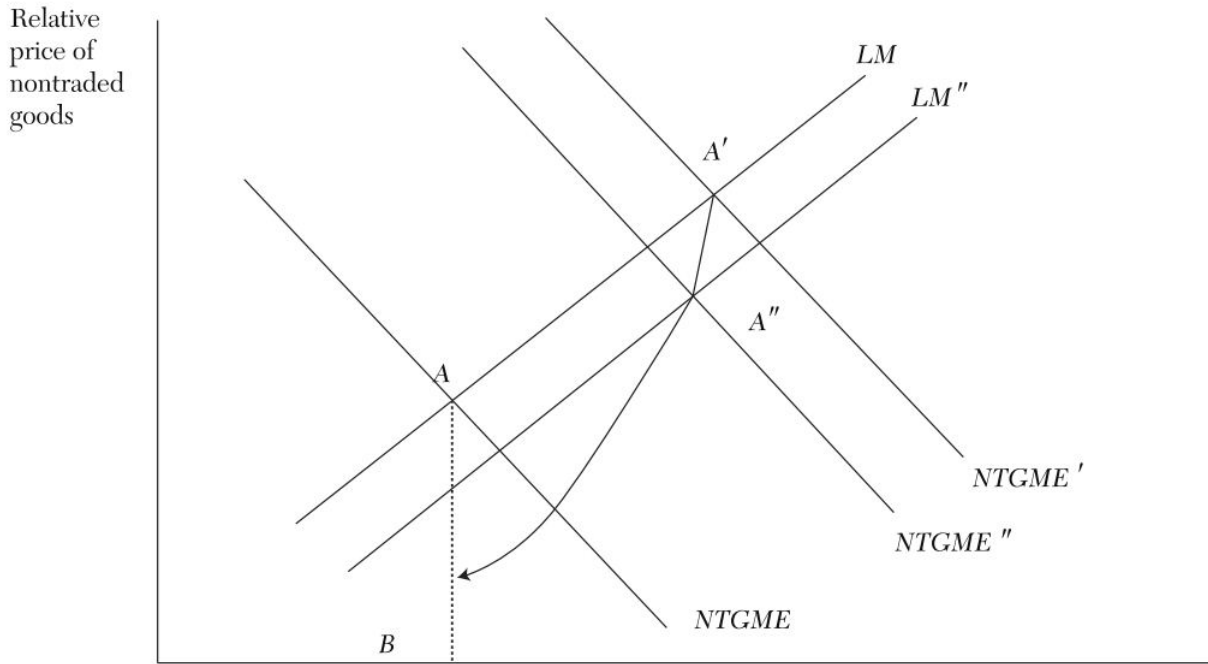
$$C_N = H_NG(L_N) \quad (4.38)$$

With intuitive notations and G also following the Inada conditions. [Van Der Ploeg \(2011\)](#) sets the labour supply exogenously to 1, so that labour market equilibrium is given by $L_T + L_N = 1$. The utility function of consumers depends on both goods, $U = (C_N, C_T)$ subject to the utility constraint in terms of traded goods price $Y = PC_N + C_T$. National income is defined by $Y \equiv PH_NG(L_N) + H_TF(L_T + H_TQE)$. Optimality requires the marginal utility of consumption of both goods to be equalised. Assuming a CES function, this yields:

$$C_N = \frac{Y}{(1 + P^{\epsilon-1})P} \quad (4.39)$$

With ϵ the elasticity of substitution between traded and non-traded goods. Let us define $H \equiv \frac{H_T}{H_N}$ the productivity of the traded sector relative to the non-traded one. Equilibrium in

Figure 4.4: Equilibrium in the economy



Source: Van Der Ploeg (2011)

the market of non traded goods is obtained for:

$$P^e = \frac{H[F(1 - L_N) + QE]}{G(L_N)} \tag{4.40}$$

This is the allocation representing the combinations of the real exchange rate P and the share L_N that clears the non traded goods market. This is noted by Van Der Ploeg (2011) as the NTGME locus. For labour to move from one sector to the other, it must be paid equally on both, which defines a cut-off condition of equalised marginal product of labour:

$$PG'(L_N) = HF'(1 - L_N) \tag{4.41}$$

Which is another allocation curve representing the combinations of P and L_N clearing the labour market. This LM curve is upward slopping, while the NGTME curve is downward slopping. A diagrammatic presentation of the expansion of the natural resource sector is presented in figure 4.4.

Assume an increase in the contribution of natural resources, an increase in QE . NTGME shifts upwards to NTGME' while LM is unaffected. The first stage of the resource boom is therefore an appreciation of the real exchange rate P while labour is reallocated from the traded to the non-traded sector. This is what Corden and Neary (1982) presented as the

resource movement effect, a general equilibrium reallocation of resources in response to price movements. This results in an increase in consumption and output of non traded goods, made possible by extra imports of traded goods. This is the spending effect. The overall impact seems positive in the short run.

For more long term effects, [Van Der Ploeg \(2011\)](#) considers an HO production structure with capital and labour. If the non-traded sector is more labour intensive than the traded sector, then the resource windfall will generate a higher wage-return on produced capital ratio. This circle being repeated in a dynamic context results in reduced use of produced capital and de-industrialisation, linked to the ever appreciating exchange rate. If, on the contrary, the non-traded sector is capital intensive, the real exchange rate will depreciate (this is the movement from A' to A'' or even B on the figure). A more complex model would be needed to frame all these effects into equations but the essence of the story is there.

Empirical evidence on the Dutch disease is somewhat mixed, but is getting more supportive of the hypothesis as samples become more detailed and/or more exhaustive ([Van Der Ploeg 2011](#)). [Ismail \(2010\)](#) in particular conducts a detailed investigation on oil exporting countries finding strongly supportive evidence for the Dutch disease. An increase in the revenues for the oil sector is accompanied by a shrinking manufacturing sector. The Dutch disease was the first manifestation of concern towards international trade and resource management. In the 1980's literature, the Dutch disease is one possibility for resource-rich countries, but those countries do not seem to react in a similar fashion.

More exhaustive samples brought forward a different hypothesis, the resource curse. The discussion on the resource curse started with the seminal article by [Sachs and Warner \(1995\)](#), followed by several publications extending the analysis ([Sachs and Warner 1997, 1999, 2001](#)). The concept originates in the negative relationship between the high ratio of natural resources exports to GDP and subsequent low growth rate. While the Dutch disease focuses on a clearly identified mechanism, the resource curse, by its very name, points towards a broad sets of consequences stemming from natural resources. It is therefore one step further towards the assumption that resource rich countries end up structurally different (at the very least).

It is by no means an accident that the idea of the resource curse is contemporary to the early development of comprehensive wealth indicators. The debate on the sources of growth, brought forward by endogenous growth models also plays a role. As in those fields, the role of international trade, central in the Dutch disease, is slowly sidelined by domestic factors. This is partly the consequence of the trend we already noted in chapter 2.⁶ Also, as in [Sachs and](#)

6. That is the tendency to focus on capital gains and the productivity enhancing role of international trade.

Warner (2001), data suggest that trade mechanisms alone cannot explain the curse. As the Hartwick rule centred sustainability issues on domestic failures, the resource curse seems to be rooted mainly in institutional problems. Papyrakis and Gerlagh (2004) show that resource abundance can have a positive impact on growth once corruption, actual starting point and the terms of trade effect are subtracted.

This would suggest that countries with structural problems happen to be resource rich and that the direct correlation is less clear cut. These potential structural problems are carefully reviewed in Van Der Ploeg (2011). We already presented in our discussion on the importance on inclusiveness in chapter 2 the key role of institutions. ? speak eloquently of the lasting impact of Spanish colonial institutions in Peru. An impressive number of articles documented the need to reduce corruption, increase inclusiveness and limit the power of vested interest (Kolstad and Wiig 2009). The literature is especially keen to avoid the concentration of political and economic power in the hands of an elite, let alone a head of state (Acemoglu et al. 2004). The history of countries such as Sierra Leone or the Democratic Republic of Congo is eloquent enough about the possibility of armed conflicts related to “blood diamonds” and other natural resources.

We saw earlier that the core of the Dutch disease is the sudden boom in resources prices and/or quantities. This assumption strikes as obvious the reader accustomed to the oil shocks and the commodities boom of the 2000’s. It also makes sense in the context of the Hotelling rule and the literature on optimal depletion paths. Still, the empirical reality may be different. The famous Prebisch-Singer hypothesis predicted a secular fall in primary product prices. Although ridiculed in the aftermath of the first oil shock, a recent contribution suggests that this could be a question of time frame, as in the very long run the hypothesis seems verified (Harvey et al. 2010).

Following this logic, countries or groups controlling resources within countries, may be tempted to deplete resources quickly as a way to extract the rent before it dies out. This could even be the case in periods such as the counter oil shocks between peaks. This kind of behaviour would lead to systematically lower and maybe negative adjusted net savings. The question then is to decide whether the original problem is the price shock or the institutional reaction. Atkinson and Hamilton (2003) explore empirically the correlation between GDP growth and resource abundance. They conclude that the investment policy by the rent owner is fundamental to determine if a country falls prey to the resource curse. They point first and foremost at macroeconomic and expenditure policy enforced in the face of resource abundance.

Another important contribution by Van der Ploeg (2010) investigates this matter further. As we stressed earlier, the open economy matters also because it allows for investment outside of

the domestic economy. Following this central lead, [Van der Ploeg \(2010\)](#) suggests amending the Hartwick rule based on the expected capital gains on reserves of natural capital, the expected increase in interest income on net foreign assets and the evolution of extraction technology. These adjustments lead to postponing the depletion of natural resources. His very comprehensive model tackles almost all of the issues presented above. He finds, in the political economy part, the expected results. The innovation lies on the definition of a "Kuwait economy" where natural resources do not enter in the production process. The challenge is therefore to deplete oil optimally to maximize the rent, not production.

The Hotelling condition derived from the model states that the social planner should be indifferent between extracting oil to invest the proceeds and get a return on capital to the world interest rate, or keeping the oil on the ground to enjoy capital gains net of marginal extraction costs. The offsetting of depletion is therefore not obtained by investment in domestic assets, but by investment in foreign assets. As noted in the article, the model of [Okumura and Cai \(2007\)](#) reaches a somewhat similar conclusion where private consumption ends-up sustained by the interest on accumulated foreign assets only. Both models exhibit a "rentier" behaviour. This behaviour is obtained by preventing direct domestic investment of the rent, which could be assumed to be impossible for political reasons or lack of opportunity. Depletion is still anchored to expectation regarding the evolution of exogenous world prices though.

It seems to us that this discussion gravitates around the problem of the scope of the analysis. What can be included in the normal functioning of economic mechanisms and therefore a) is the object of study and b) is subject to the rest, the "exogenous variables". In this perspective, familiar from chapter 2, economic mechanisms are self-correcting when optimal, and subject to external forces: property rights, wealth distributions, institutional arrangements, political culture and organisation. As we made it clear before, we believe this methodologically useful distinction should not be used in a sustainability context. It introduces a framing bias in the problem by somewhat arbitrarily separating economics and variables that at the very least can be affected by economic outcomes. Studying international trade and sustainability requires answering the question: to which extent do trade-induced specialisation patterns have an impact on the institutional setting supporting sustainability? This feedback effect of trade cannot be ignored.

We saw that the set of countries characterised by natural resource abundance faces issues that are either unique to those countries, or far more prevalent than in resource poor ones. We followed the literature which clearly identifies factors sourced in domestic characteristics which seem to be prominent in the resource curse debate. These factors have to do with inclusiveness, corruption and macroeconomic and expenditure policy. We believe that the possibility that

resources rich countries are structurally different *also* because of resource abundance-induced trade patterns should be explored. Emphasising this, we merely say that trade patterns should not be treated as a constraint on institutional arrangements. Trade patterns should be altered to preserve institutional arrangements. Hence, trade patterns should be assessed and then fostered or curbed, depending on sustainability constraints.

In that sense, we impose the normative sustainability approach on observed or predicted trade flows and the analysis of international trade. The literature also recognised in the discussion on the Dutch disease the importance of trade-induced behaviour, that we would split between direct and indirect consequences. The direct impact of trade is the impact on patterns of specialisation in endowments. This effect is the resource allocation effect in Neary and Purvis (1982) and the composition effect in Copeland and Taylor (2003). The effects are different as the modelling is different but the logic is the same.

The importance of the direct impact is linked to a vision of “secular movements” in international trade. The one critical to our topic is the evolution of world prices for primary resources. If resource prices regularly increase in a context of increased scarcity, only contained by backstop technologies, then countries specialised in resources should probably rely on this specialisation and focus on optimal management. If a Prebisch-Singer situation is more likely, then the main goal of those countries should be to undertake structural changes and find other comparative advantages.

In the meantime, primary resources specialisation is more likely to be a curse, a dwindling but critical and non perennial instrument of wealth. The possibility of a lock-in which soon contaminates the institutions and market mechanisms via rent-seeking behaviours is real. We see here that no matter what the actual “secular movement” might be, the same sort of behaviour can be expected from rent owners. It might be worth reconsidering the articulation of specialisation and the old idea of imports substitution.

The indirect impact presents other challenges. The indirect impact is the induced decorrelation in interest in international trade, with the possibility to invest and consume in other countries. Although it may look optimal in a narrow economic perspective to invest some of the natural resource abroad, it can be detrimental to the political equilibrium built around resource extraction. The spatial decorrelation between factor usage and income is especially problematic in the context of a potential internal struggle, as it may regulate the direct access to wealth and income, critical to maintaining inclusiveness and the balance of power. In this perspective, trade openness can be a useful way to prevent economic over-heating and domestic wasteful investment, but can further distort the distribution of wealth and the political state of affairs. International trade exacerbates the dependence of the national economy on a sector or

even a single resource, creating imbalances inside the country, resulting in regulatory capture, if not plain transfer of political power. This results in policy in favour of the sector, discouraging innovation and growth in the other sector, and in time the enforcement of extractive institutions. In the end, these extractive institutions bring growth to a halt.

These elements reinforce our conclusion that trade movements and institutions are two sides of the same sustainability coin, needing joint treatment. This is not without hurdles, as the objection of [Arrow et al. \(2010\)](#) about the lack of a “co-evolution theory of institutions” reminds us. But failing to appraise both simultaneously would lead us to have institutional evolutions destroyed by positive or negative direct and indirect effects of international trade. Conversely, a potentially positive swing in resource prices would be thwarted by extractive institutions. Consistency in sustainability requires, falling short of an integrated theory, a political economy co-treatment of both issues. According to [Van Der Ploeg \(2011\)](#), the basis of the success stories against the resource curse (as in Botswana, Thailand, Indonesia or Malaysia) are diversification, high wages, complementarities between manufacturing and extraction. These are the signs of sound structural change, and cannot be reached by political reforms or market mechanisms alone.

Resource-rich countries trade and institutional profile are therefore impossible to disentangle. Still, this would mean that resource rich economies would exhibit similar trade and institutional patterns. Without being able to directly test this proposition on co-evolution we can still use our previous conclusions to suggest amendments to empirical estimates of the resource curse, in line with sustainability studies.

II.2 Resource abundance and the patterns of resources trade

Previous attempts to estimate the consequences of natural resources abundance have focused on the impact on the GDP growth rate. This is the core of the resource curse study. Under the resource curse, international trade is only one factor, although an important one, in explaining lagged performance in resource rich countries. Our ambition is to investigate the role of international trade as the corollary of institutional arrangements, considered in the literature ([Atkinson and Hamilton 2003](#), [Van Der Ploeg 2011](#)) to be the key factor. We framed our presentation of countries in terms of specialisation and investment strategies in chapter 3. Similarly, [Ethier \(1982\)](#) proposed archetypal countries based on the nature of trade flows.

We will base our test on the importance of trade as an explanatory factor for specialisation patterns. Usual tests of the resource curse include trade variables such as openness, variations

in terms of trade and the share of manufacturing in total exports (Sachs and Warner 1997, 2001). As explained by Sachs and Warner (2001), these tests are centred on the notion that natural resource abundance, as in the regular Dutch disease, crowds out other forms of economic activity (Harding and Venables 2013). This should make our difference in philosophy clear. We do not consider this to be a crowding out effect, we believe this to be an expectable consequence of international trade incentives on industrial specialisation. To be clear, we do not dispute the reality of the results. We merely believe that they need to be read in the context of international interdependence and structural change. In this context, a pattern of trade can be the product of distorted domestic management, but no more than distorted domestic management is the product of patterns of trade shaped by the conditions of globalisation.

An oversized natural resource sector seems impossible to avoid when strongly encouraged by trade incentives. For example, Kuralbayeva and Stefanski (2013) present a model inspired by the Salter-Swan model stressing that causality in specialisation starts from the reallocation of resources (labour) to the natural resource sector resulting in smaller size of manufacturing and rising productivity, not the other way around. These trade induced effects on the domestic structure of production are somewhat overlooked in the discussion and we would like to address this in this section.

On the course of structural change, countries are expected to balance their use of the instruments of wealth. This implies going from high asymmetry in endowments to low asymmetry. This result can be obtained via the shrinkage of natural resource use with respect to the emerging reliance on produced and human capital. Alternatively, it can be obtained with constant or increasing natural resource use, but in the context of a more than proportional increase in the use of other instruments. It is then not so much the absolute but relative use that is declining. In the end, both ways generate reduced asymmetry in endowments. In chapter 3 we stressed the link between the level of asymmetry and the pattern of trade. In table 4.2 we present an illustration of the link between our measure of asymmetry from chapter 3 and the resource rent as a percentage of GDP in a selection of countries for the year 2000.

Under our working hypothesis that domestic and trade factors are at work together in creating this category of resource intensive countries we need to go beyond the traditional HO conclusions. Considering inter-industry trade, tests of the HO prediction taking productivity differences into account yield robust results, available in Treffer (1993) and Treffer (1995). We saw that for the needs of sustainability assessment, increasing returns to scale need to be considered without exogenous improvements in productivity. Following this assumption Antweiler and Treffer (2002) explore the predictive power of taking increasing returns to scale

7. As a percentage of GDP.

Table 4.2: Synthetic asymmetry results

Country	% Country 1	% Country 2	2005 rent ⁷
Uzbekistan	1.8397535	98.1602465	105.916563
Congo, Rep.	3.81127981	96.1887202	74.7260454
Brunei Darussalam	10.3769444	89.6230556	67.5211743
Angola	15.2689776	84.7310224	65.8734427
Azerbaijan	28.2707109	71.7292891	65.0217006
Brazil	67.4048681	32.5951319	6.00663863
India	60.4134331	39.5865669	5.54025533
The Netherlands	95.4956506	4.50434945	2.43423001
New Zealand	77.8761134	22.1238866	2.02620284
Albania	81.2012448	18.7987552	1.75427272
Armenia	79.581614	20.418386	0.92227285
Belgium	98.1376334	1.86236655	0.03442522

Source: Author's calculations from the World Development Indicators (WDI)

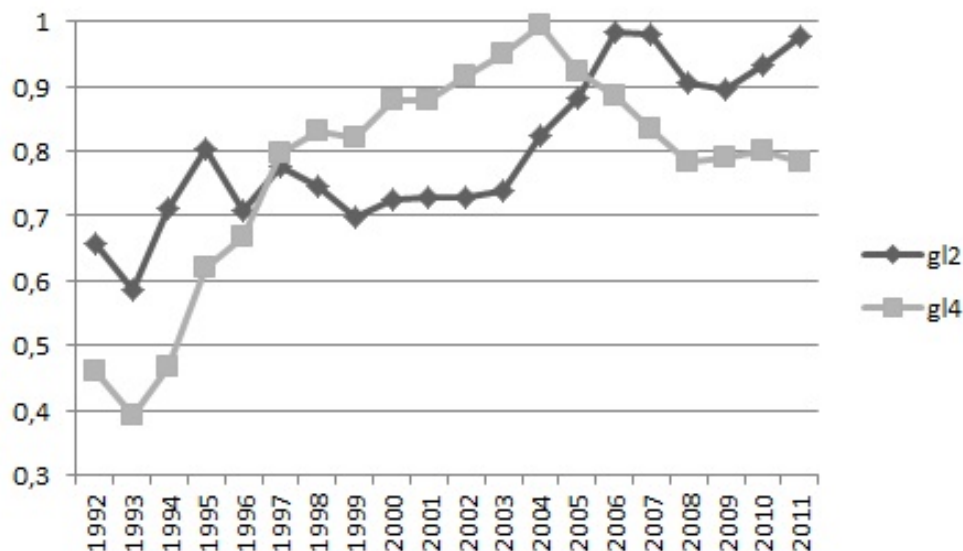
into account. They find the consideration of IRS to help considerably in predicting trade flows.

This concurs with the observation of [Evenett and Keller \(2002\)](#). Using a gravity framework, they show that intra-industry and inter-industry trade are likely to be at work simultaneously and that both need to be considered to explain trade flows accurately. More importantly, [Antweiler and Trefler \(2002\)](#) find statistically significant increasing returns to scale in both manufacturing and natural resources. All these elements concur to say that beyond the standard HO prediction, there is no reason for resource rich economies not to trade under a diversified pattern within their broadly defined comparative advantage.

Resource-rich countries can be categorised as country 2 types in low asymmetry and then intra-industry trade should be dominant if any trade is to happen at all, across all production goods considered. If there is high asymmetry in type 2 countries, then they should exhibit a secular trend towards a more diversified export structure (controlled for variation in global prices if they can be considered exogenous) as they enter the global supply chain and benefit from the international division of labour. A good example of this is China, a country doubtlessly undertaking a form of structural change. As [figure 4.5](#) shows, the pattern of trade in intermediate goods (index gl2) and capital goods (index gl4) diversified over the years.

Index gl2 and gl4 are computed using the [Grubel and Lloyd \(1975\)](#) index of intra-industry trade. We have been discussing intra-industry trade somewhat loosely until now and precisions are in order. Intra-industry trade is always defined relatively to a grid of industries and goods, usually along the lines of international classification. A definition of intra-industry trade is

Figure 4.5: Patterns of trade in China



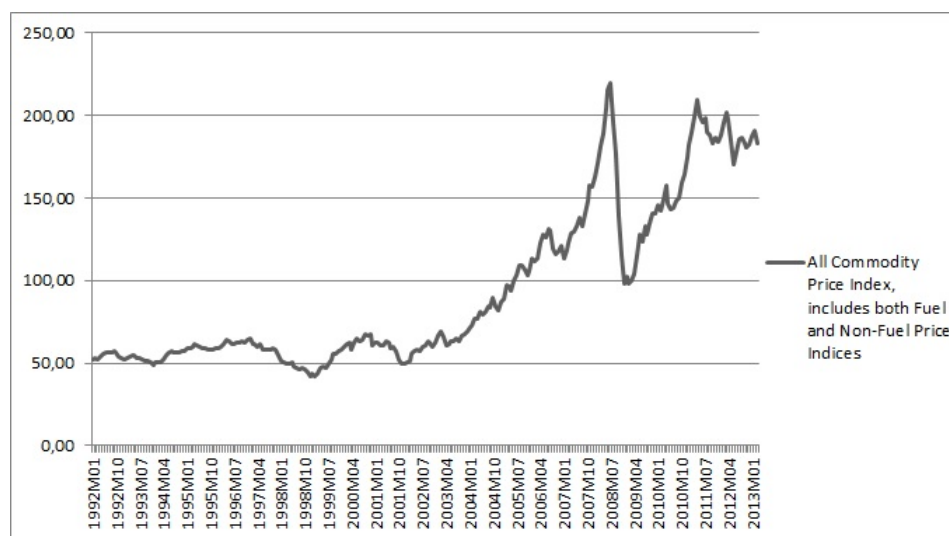
Source: World Development Indicators (WDI, Comtrade, author's calculations)

therefore always dependent on the level of aggregation associated with the classification involved. Intra-industry trade is therefore linked to a degree of sameness. These elements in mind, it would be abusive to talk of intra-industry trade *per se* in the rest of the section, as we consider a high level of aggregation (4 categories). It is probably more accurate to talk about one way (inter-industry) and two ways (intra-industry) trade, which we will use from now on. We will use the Grubel-Lloyd indexes as indicators of the prevalence of two ways trade, as in the example of China above.

True to our working hypothesis, we would like to investigate the correlation between resource abundance and trade patterns using two regressions. The first test is centred on resource abundance itself. We investigate whether countries identified as resource abundant can be associated with a given pattern of trade in a statistically significant way. We control for common variables in the context of the resource curse in order to determine whether patterns of trade can be associated with resource abundance. The second test investigates whether resource rich economies exhibit a distorted relationship with inter-industry (two ways) trade in resource intensive goods compared to non-resource rich economies.

To do this we investigate whether the pattern of trade in natural resource intensive goods, regrouped under a common bundle, is impacted by resource abundance controlling for the pattern of trade on other bundles. These two tests should allow us to determine if resource abundant countries enter international trade in line with the traditional HO prediction, or in a different fashion. In statistical terms, we want to identify the correlation between the

Figure 4.6: Global commodity prices



Base year 2005=100

Source: Global Economic Monitor (GEM) Commodities

observed heterogeneity in resource abundance between countries, and a hypothetical correlated heterogeneity in trade patterns. What makes this observation complex is the fact that it cannot be done on an inter-industry basis only. If so, it would be a test of the HO prediction. This is the rationale for our focus on one way and two ways trade, based on the results of the model in chapter 3.

The evolution of commodity prices is another important issue to be addressed. Although energy and fuel saw the bulk of the increase, the rise in commodity prices is largely demand driven. This trend can only reinforce the tendency of resource rich countries to enter international trade on an inter-industry (one way) trade basis. This should generate income gains in the short run by the mechanical action on the terms of trade. But, the very logic of inter-industry trade encourages resource rich countries to rely on this first comparative advantage and precludes movement towards intra-industry trade by rising the opportunity cost of transition. Pittel and Bretschger (2010) investigated this in the context of the links between resource intensity in production and biased technical change. We should take this context of increasing prices into account for our tests.

II.3 The data

The relationship, as stressed by the literature presented above, cannot be considered in isolation of other general equilibrium effects. We base our choices of variables to take these effects into account on the models presented before, [Lederman and Maloney \(2003\)](#) and [Sachs and Warner \(2001\)](#). An exhaustive presentation of the data and sources is available in appendix I.

The main variable of interest is resource abundance in the considered country. We depart from [Sachs and Warner \(2001\)](#) who use natural resource exports as a share of GDP. This variable, although better than other proxies can cause problems in the context of small countries with a strong re-exporting base ([Lederman and Maloney 2003](#)). It would also overlap with our other variables, since the volume and the patterns of exports in natural capital could be related. Therefore, we use instead resources rent as a percentage of GDP. Data is extracted from the Wealth Accounting database of the World Bank, for the years 1992 to 2010. The usual caveats with rent data apply, most notably because rent is calculated using the difference between the average cost and the resource price, instead of the theoretically relevant marginal cost.

Our endogenous variable for the second test is the respective share of inter-industry (one way) and intra-industry (two ways) trade in natural capital intensive resources. In line with most of the literature since [Grubel and Lloyd \(1975\)](#), we compute this value using the Grubel-Lloyd index. We use the World Integrated Trade Solution (WITS) portal to extract data from the COMTRADE database. Our dataset is based on the HS 1988/92 classification. Trade flows are regrouped under four bundles codenamed UNCTAD-SoP. The Bundle SoP1 regroups raw materials, SoP2 is for intermediate goods, SoP3 for consumer goods and SoP4 for capital goods. We extract imports and exports from a given country to the rest of the world between 1992 and 2011. The Grubel-Lloyd index [Grubel and Lloyd \(1971, 1975\)](#), is computed using the formula:

$$GL_{i,t} = \frac{(X_{i,t} + M_{i,t}) - |X_{i,t} - M_{i,t}|}{X_{i,t} + M_{i,t}} = 1 - \frac{|X_{i,t} - M_{i,t}|}{X_{i,t} + M_{i,t}}; 0 \leq GL_{i,t} \leq 1 \quad (4.42)$$

If $GL_{i,j} = 1$ trade between the two countries in the sector i in year t is only intra-industry. If $GL_{i,j} = 0$ it is only inter-industry. This gives us four Grubel-Lloyd indexes over 20 years per country.

The interactions between these two variables are the core of our two tests. We obtain data for a selection of 177 countries, based on availability. We then divide this sample between 3 groups. A first group (g5) is composed of countries earning rents equal to more than 5% of

GDP on average over the period. It amounts to 50 countries. The second group (g2) is the first group plus countries earning rents between 5% and 2% on average. It amounts to 87 countries. The remaining 90 countries are left out as we consider countries earning less than 2% of GDP in natural resource rent irrelevant to our study.

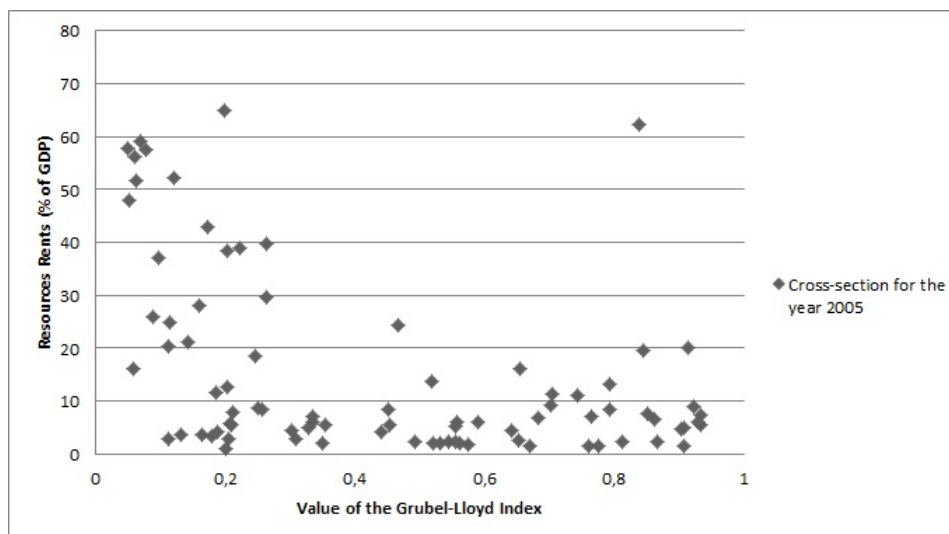
We plot the relationship between resource abundance and the Grubel-Lloyd index for raw materials in 2005 for group g2. This is represented in figure 4.7. Graphically we see a moon-shaped negative relationship between resource abundance and two ways trade in raw materials. To test the validity of this first impression, we propose to run a regression on our two samples g5 and g2. The relationship could be framed in terms of the scenarios from chapter 3. Consider figure 4.8 where we split the relationship between four quadrants. In the top two quadrants, countries are resource abundant, which makes them country 2 type countries. In the bottom two quadrants countries are resources scarce, which makes them country 1 type countries.

In quadrant 1 countries are resource abundant and engaged in one way trade which casts them into the CA scenario. They seem to be exploiting their comparative advantage in natural capital and using it to buy goods in industries where they have a comparative disadvantage. In quadrant 2 are countries which, while still resource abundant, are developing two ways trade in raw materials. These should be countries in CA but more likely in a low asymmetry setting. There are almost no countries in this quadrant, which makes sense since we predicted that countries in CA and low asymmetry had little incentive to trade. The few doing it are effectively doing so on a two ways basis.

In quadrant 3 are resources scarce countries which are still relying on one way trade in raw materials. This seems like the critical area where countries with an advantage in natural resources switched to the SC scenario and started to significantly deplete natural assets, hopefully building produced capital with the proceedings. Finally, in quadrant 4 are resource scarce countries engaged in two ways trade. These are countries in SC and low asymmetry since they have enough natural resources to engage in two ways trade.

The disposition of points across the two samples in this year gives us precious insight on countries strategies regarding structural change. It would effectively bring countries from quadrant 1 to 4. But this journey could be undertaken in two ways. The first path involves following a CA strategy where sustainable management of resources brings country two type countries from quadrant 1 to 2. Sound management of the resources allows reinvestment and development of intra-industry trade. If this interpretation is correct, we should see a positive relationship between two ways trade in raw materials and two ways trade in the other bundles, notably intermediate goods. Then, as the total wealth in the country increases faster than the value of natural resources, the share of resource rent in total output diminishes, bringing the

Figure 4.7: Resource abundance and two-way trade in natural resources



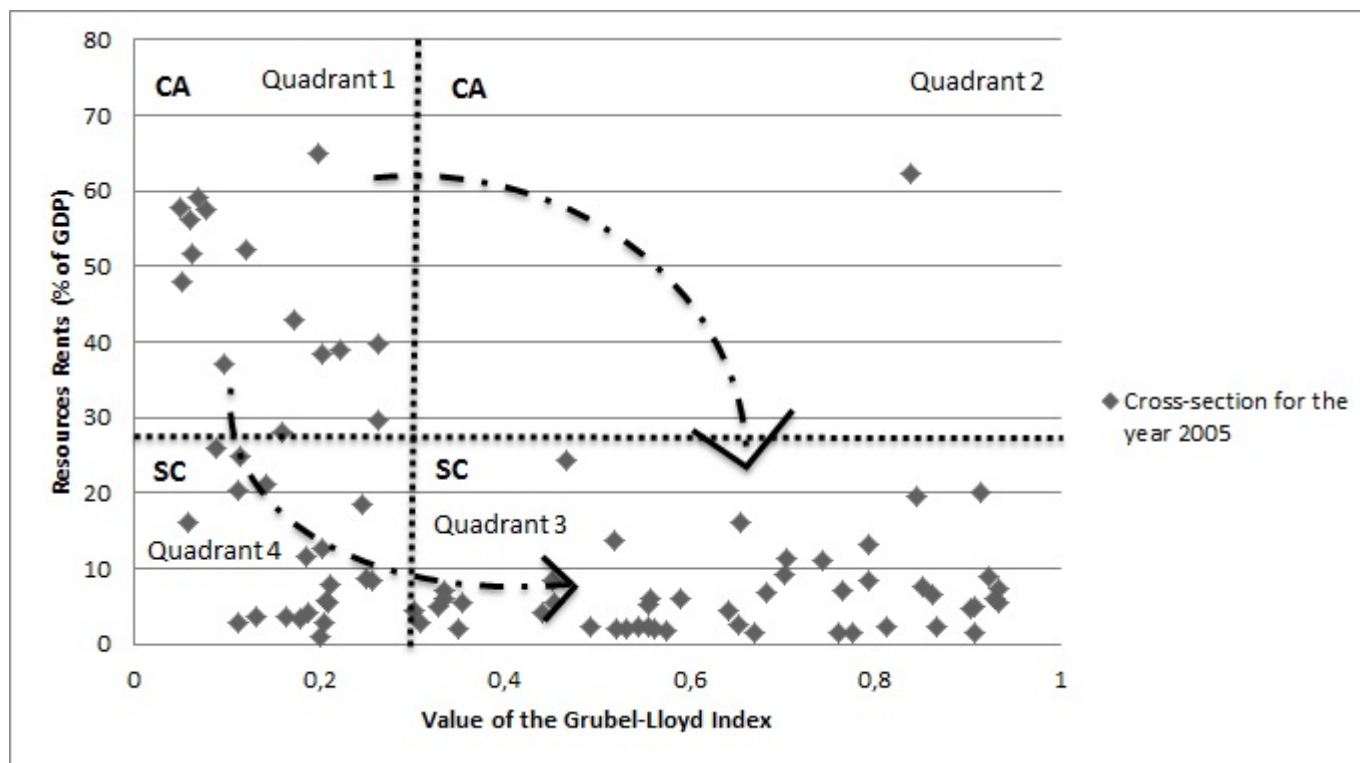
Source: Author's calculation from the Wealth Accounting and Comtrade Databases

considered country slowly from quadrant 2 to 3, where natural resources are still significant in absolute terms, but not so much in relative terms.

The second path involves unsound management of the rent so that the share of resource rent in total output declines before the industrial orientation actually changes. Country 2 type countries go from quadrant 1 to quadrant 3. From there, they have to keep depleting the natural capital they have left to obtain the resources to diversify their industry, as they start to need more and more imports of natural capital which are no more compensated by their exports of natural capital intensive material. They then move through this mechanism to quadrant 4.

Both paths involve factor intensity reversal when going from the top quadrants to the bottom ones. The difference is when it occurs and the consequences for wealth accumulation. The first structural change path with proper maintenance of natural capital makes for a smoother transition where sustainable instruments of wealth are built before exhaustible ones are depleted. But the data suggest that countries wait for resource scarcity to bite in quadrant 3 to undertake in the worst possible conditions and with the least resource, a transition they cannot control. The number of countries taking the "ideal path" through quadrant 2 is obviously dependent on the definition of the limits on the quadrants. Observing the dynamic plots of the data still suggest that most countries with the possible exception of Trinidad and Tobago, take a path more akin to the second one. The dataset also suggests that countries can go from the bottom quadrants to the top ones. The undesirability of this scenario is made obvious by the fact that they systematically join quadrant 1 when doing so. To validate this interpretation, we should therefore find a statistically significant negative relationship between

Figure 4.8: Paths for structural change



Wealth Accounting Database, Comtrade, Author's calculation

resource abundance and two ways trade in raw materials. To validate the intuition that two ways trade in raw materials is a marker of industrial diversification and reduced asymmetry, we should also at least observe a possible relationship between the index for raw materials and the index for intermediate goods.

A test using such macro-level data requires variables to control for general equilibrium effects and potential biases. In the literature on the Dutch disease, resource abundance is associated with a shrinking manufacturing sector. To test for the co-evolution of manufacturing, we propose two variables. The first is manufacturing value-added as a percentage of GDP. it seems suitable to control for the impact of resource abundance on manufacturing in the first test. We obtain this data from the World Development Indicators (WDI). This variable should capture the evolution of overall manufacturing in domestic production and therefore control for reallocation of resources in response to domestic factors. The second variable is more suitable to the second test on the response to variations in the pattern of trade. We use the Grubel-Lloyd index on the second bundle SoP2 for intermediate goods. A value close to one would indicate a diversified manufacturing base, even if its overall size is small (Kuralbayeva and Stefanski 2013). This would indicate whether one way trade in raw materials is associated with one way trade in intermediates or not. We also include for consistency the Grubel-Lloyd index

on the fourth bundle SoP4 for capital goods. If our hypothesis on the occurrence of exports diversification is true, this variable should follow the movements of the index from the SoP1 and SoP2 bundles. In the early stages of structural change when resource dependence is high, countries should engage in one way trade in both intermediates and capital goods, following an inter-industrial trade pattern.

Optimally, we should both control for the evolution of asymmetry as a driver of the patterns of trade and a control for the importance of the resource sector. But data on natural capital are only available for the years 1995, 2000 and 2005, which would narrow our period of study too much. Another natural control variable is the growth rate of GDP. This would link our test to the rest of the literature on the resource curse and help us capture the impact of the underlying increase in wealth and income on the structure of exports. When the share of manufacturing allows us to control for resource relocation between sectors, the growth rate of GDP will allow us to control for the overall increase in wealth and income. We obtain this from the World Development Indicators. We also stressed the role of commodity prices movements for exports patterns. Therefore, we also control for commodity prices using the all commodities price index from 1992 to 2011, from the Global Economic Monitor (GEM) Commodities database. Similar to the growth rate, we control for the increase in the volume of trade. The modification of the structure of exports could be generated by an exogenous increase in productivity *ceteris paribus*. Since resources abundant countries may experience unbalances in productivity gains between sectors, this should be controlled for. To do this, we use the volume of total trade as a share of GDP, from the World Development Indicators.

II.4 Model and Results

Our data covers 20 years and up to 87 countries. We plot the mean values for our samples per year and per countries for our two variables of interest, resource abundance (rr) and pattern of trade in raw materials ($gl1$). The results are available in figures 4.10 for the means per year and 4.9 for the means per country for variable $gl1$. Correspondingly in figures 4.12 and 4.11 for variable rr . We observe strong heterogeneity across countries and years for all samples for the variable rr . The variable $gl1$ is characterised by increasing cross-country heterogeneity as the size of the sample increase, while cross-years heterogeneity is much milder and does not seem to depend on sample size.

Figure 4.9: Heterogeneity across countries for the Grubel-Lloyd index in raw materials

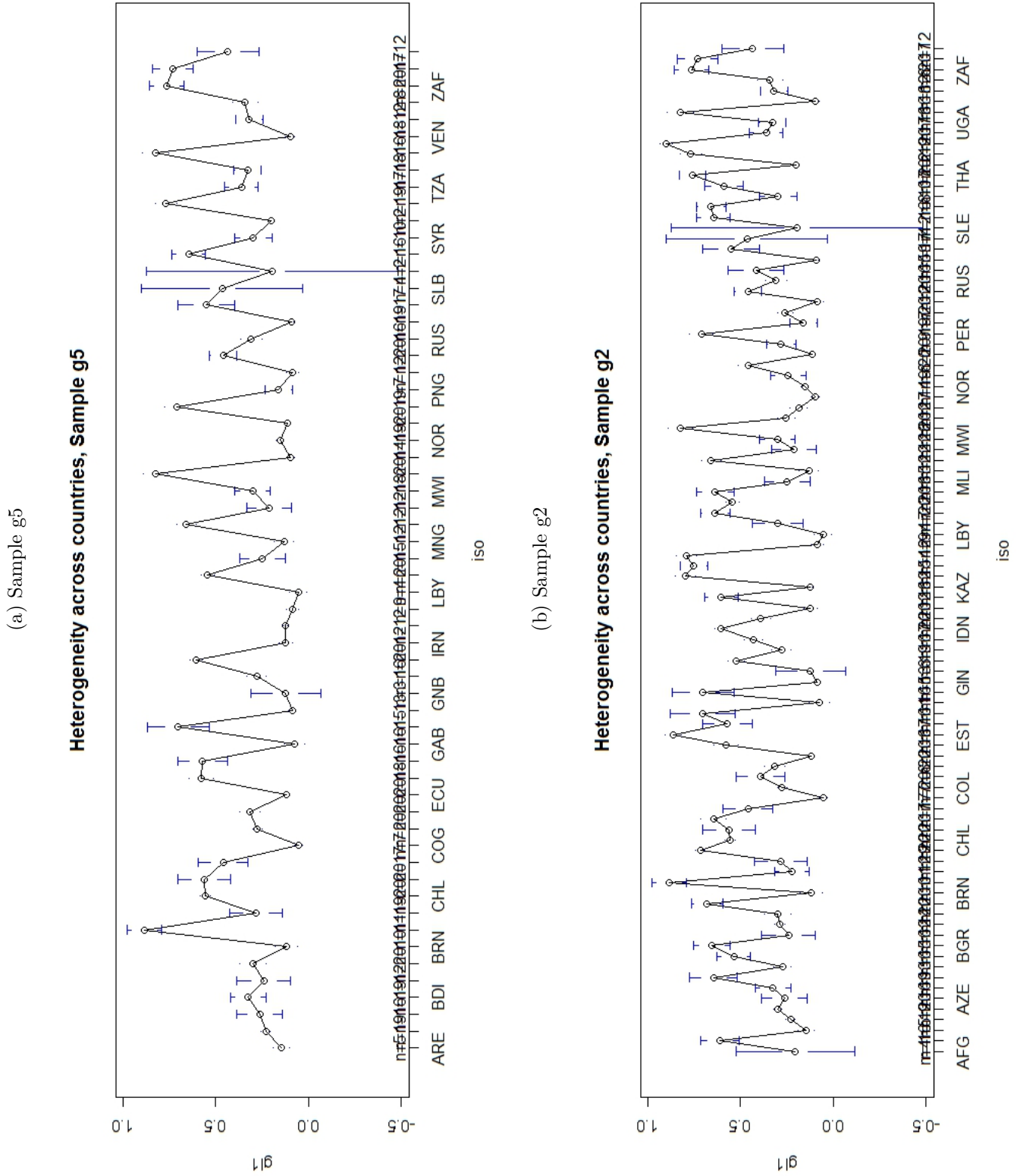


Figure 4.10: Heterogeneity across years for the Grubel-Lloyd index in raw materials

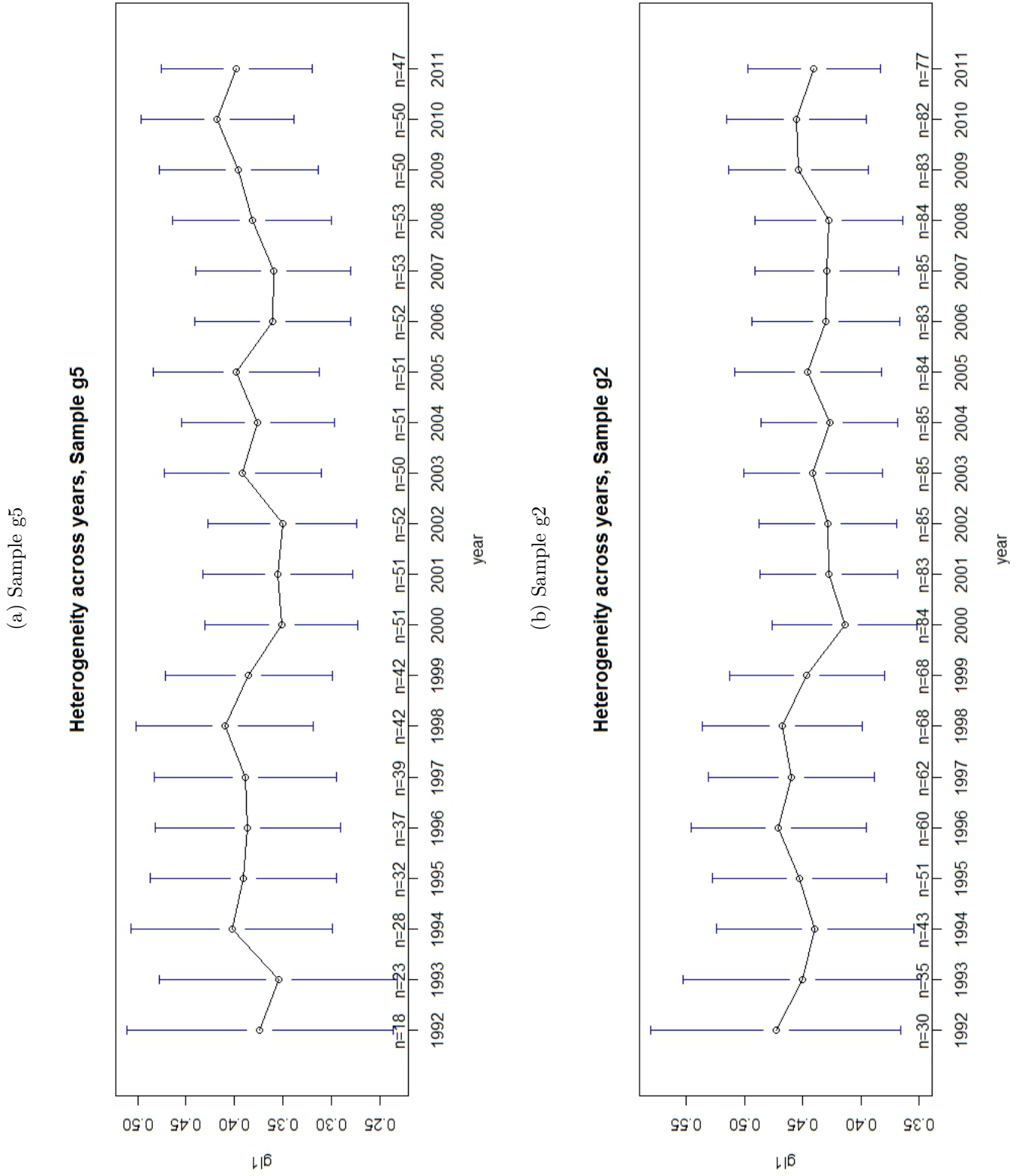


Figure 4.11: Heterogeneity across countries in resource abundance

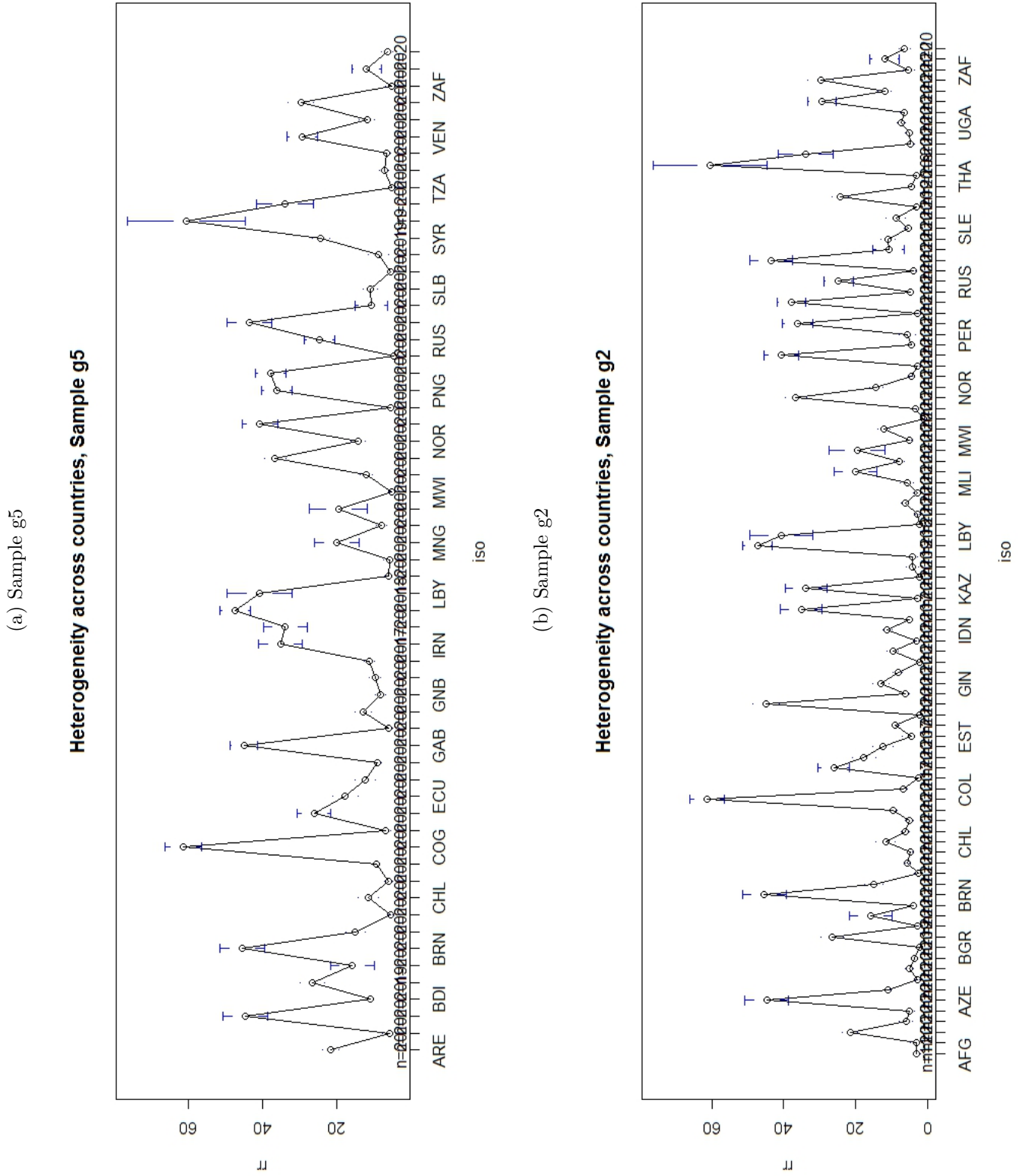
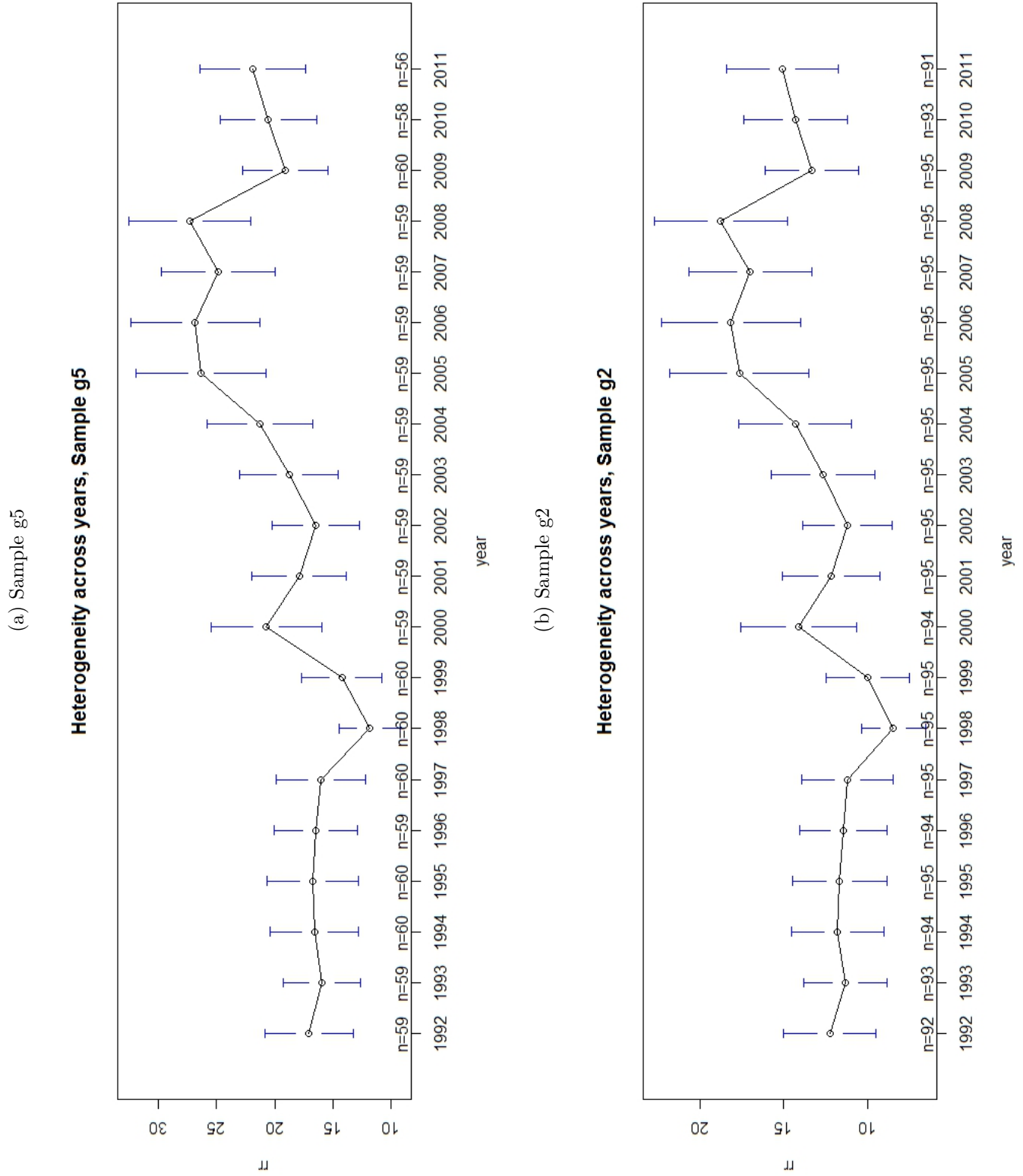


Figure 4.12: Heterogeneity across years in resource abundance



The correlation matrices and descriptives statistics for the different sample sizes are available in appendix G. True to our strategy to control for the two-way causation, we test the two generic regressions:

$$rr_{i,t} = \alpha + \beta_1 gl1_{i,t} + \beta_2 gl4_{i,t} + \beta_3 vt_{i,t} + \beta_4 gg_{i,t} + \beta_5 man_{i,t} + \beta_6 cp_t + \epsilon_{i,t} \quad (4.43)$$

$$gl1_{i,t} = \alpha + \beta_1 rr_{i,t} + \beta_2 gl2_{i,t} + \beta_3 gl4_{i,t} + \beta_4 vt_{i,t} + \epsilon_{i,t} \quad (4.44)$$

With *cp* the all commodities price index, *gl1* the Grubel-Lloyd (GL) index for raw materials, *gl2* the GL index for intermediate goods, *gl4* the GL index for capital goods, *man* manufacturing value added as a percentage of GDP, *rr* natural resource rent as a percentage of GDP and *vt* the volume of trade as a percentage of GDP. We test both equations through the same strategy. Starting with sample *g5* composed of 57 countries, we test the pooled OLS model using the Breusch-Pagan LM test (Breusch and Pagan 1980) and find the effects to be significant for both regressions. We then use the Hausman (1978) test to discriminate between fixed and random panel effects and conclude in favour of fixed effects for both regressions.

We then test both models for cross-sectional dependence with the original Breusch and Pagan (1980) statistic and the Pesaran (2004) statistic. We find significant cross-sectional dependence for both regressions. We then test for serial correlation in the idiosyncratic component of the errors. We use the Breusch (1978) test and perform it for order 1 and 2 autocorrelation. We find significant autocorrelation of order 1 and 2 in both regressions. Considering the importance of a proper treatment of autocorrelation in panel data, we use the Durbin-Watson and Wooldridge tests for autocorrelation in fixed effects panel data models (Wooldridge 2002) and find the same statistically significant autocorrelation.

We test heteroskedasticity using the Breusch and Pagan (1979) test with studentized residuals following Koenker (1981). We find evidence of heteroskedasticity in both regressions. We found cross-sectional dependence, heteroskedasticity and autocorrelation, resulting in biased estimators. To control for this, we apply the variance covariance matrix as in Arellano and Bond (1991) with a clustering over time option to control for cross-sectional dependence. Those corrections yield model 1 in tables 4.3 and 4.4.

The need to cluster observations over time to control for cross sectional dependence suggests that time fixed effects might be relevant. We compare the F-statistics from the pooling, two-ways and time fixed effects regressions and conclude that both time and individual fixed effects should be included in both regressions. The variable *cp*, is unsurprisingly strongly correlated with time fixed effects, the point of collinearity. As a consequence, we drop it from regression 4.43 and use time fixed effects instead. We then run the same tests for cross-sectional dependence,

heteroskedasticity and autocorrelation and find evidence of all three. We then control for this using the same robust variance covariance matrix which yields model 2.

Considering the persistence of autocorrelation with two-ways fixed effects, we control for unit roots in our variables using the [Levin et al. \(2002\)](#) test for panel data. We conclude that some of our variables have a unit root. We then use the advanced Dickey-Fuller tests ([Fuller 1976](#), [Said and Dickey 1984](#)) to obtain the order of autocorrelation. We conclude that the lags of our endogenous variables in both regressions need to be included. We then run the [Breusch \(1978\)](#) test which allows to test for autocorrelation for orders higher than 1 and find significant autocorrelation at 1% for all orders in both regressions. However, running the Durbin Watson and Wooldridge tests we find no significant autocorrelation in regression 4.44 and autocorrelation in only one of the two tests for regression 4.43. We still find evidence of heteroscedasticity and cross-sectional dependence, so that we apply the robust variance covariance matrix which gives us model 3.

The inclusion of lagged variables into a fixed effects regression leads to a dynamic panel bias ([Nickell 1981](#)). OLS estimators might not be asymptotically convergent when lagged variables are included as robust variance covariance matrix controls for autocorrelation between regressors and errors, but not between regressors in t and $t - 1$, let alone higher orders. This is an especially great concern considering the order of autocorrelation suggested by our unit root tests. We therefore need to estimate our regressors using an instrumental variable approach. The standard in the literature on dynamic panel data is to use system GMMs. Originated by [Arellano and Bover \(1995\)](#), [Arellano and Bond \(1991\)](#), [Blundell and Bond \(1998\)](#) and [Holtz-Eakin et al. \(1988\)](#), the method is presented by [Wooldridge \(2002\)](#) and [Roodman \(2009b\)](#). GMM system estimation is especially relevant amongst instrumental variable approaches in the case of “large N, small T”, panels with a large number of individuals but a short time horizon. Considering the length of our sample (20 years) it is likely as [Roodman \(2009b\)](#) suggests, that the fixed effects may be able to absorb autocorrelation, so that the standard two stage least square (2SLS) instrumental approach would yield convergent estimators. We therefore propose model 4, the 2SLS regressions as an indication of the prevalence of autocorrelation in the models. We find this comparison especially important in the context of the arbitrariness associated with the choice of instruments in system GMMs.

To pick our instruments we follow the recommendations in [Roodman \(2009a\)](#) regarding the importance of the robustness of the difference in Hansen test. The problem of correlation between lagged differences used as instruments and current errors in level is obviously central here, considering the results of the autocorrelation tests in the previous models. We use the difference in Hansen test as a guide for the choice of our instruments, resulting in the following

specifications. For sample *g5* we use a two-step GMM system with robust errors for both regressions. In regression 4.43 we have 60 instruments for 57 individuals and 741 observations. We use the lagged values of *rr* and *gl4* as GMM-type instruments. In regression 4.44 we have 62 instruments for 58 individuals and 768 observations. We use the lagged values of *gl1* and *gl2* as GMM type instruments for both level and difference equations. For sample *g2* we use one step system GMM with robust errors for regression 4.43 and two steps system GMM with robust errors for regression 4.44. In regression 4.43 we have 80 instruments for 93 individuals and 1240 observations. We use the lagged values of *rr*, *gl1* and *gl4* as GMM-type instruments for the first differences equation and the lagged values of *rr* in the level equation. In regression 4.44 we have 81 instruments for 94 individuals and 1257 observations. We use the lagged values of *gl1*, *gl2* and *vt* as GMM-type instruments for both equations. In all regressions we keep time fixed effect as a control for cross sectional dependence.

Tables 4.3 and 4.4 summarise the 5 models for the *g5* sample. Fixed-effects (individual and time fixed effects for both samples and regressions) are presented in appendix H. Unsurprisingly, countries with the greatest resource abundance also have the more important positive individual fixed-effects in regression 4.43. Highest values are recorded in model 3 for Kazakhstan, Libya, Saudi Arabia and Turkmenistan. Time fixed effects are also varying strongly, with the highest values concentrated in the second half of the sample. This is an indication that time fixed effects are capturing resource prices, as the one year in the 2000 decade where resource prices fell dramatically is also the year with the smallest fixed effect of all. In regression 4.44 the time fixed-effects are much more regular in model 3, suggesting that they may be dropped (as we will do in model 5). Individual fixed-effects are highest for countries that differ from the list in regression 4.43 with Bhutan, Trinidad and Tobago and Zimbabwe.

We follow the same procedure for sample *g2*, whose characteristics are similar to sample *g5*. Tables 4.5 and 4.6 show the 5 models for sample *g2*. The spread between the smallest and the largest individual fixed effect is wider for regression 4.43 and 4.44. This makes sense as widening the sample on the bias of resource abundance should widen the gap between countries from sample *g5* and newcomers. Time fixed effects are smaller than under sample *g5* for regression 4.43. As in the sample *g5*, variations in time fixed effects are small for regression 4.44. Individual fixed effects follow the expected pattern with new countries having lower values than countries from sample *g5*.

Table 4.3: Model 1 to 5 for regression 1 sample g5

	Model 1	Model 2	Model 3	Model 4	Model 5
lag(rr)			0.732806*** (0.074914)	0.761348*** (0.116999)	0.746758*** (0.097442)
gl1	-3.355378** (1.298318)	-4.110716*** (1.110792)	-1.822040* (0.886025)	-3.957981 (3.826604)	-4.829866* (1.918752)
gl4	3.977309* (1.695577)	1.552574 (1.406175)	1.685772 (1.442188)	4.389548 (5.985293)	10.93009** (3.89853)
gg	0.282560*** (0.083675)	0.124164* (0.061906)	0.077986 (0.057921)	0.098270 (0.150522)	0.121313+ (0.073213)
man	-0.480344*** (0.112033)	-0.495173*** (0.111854)	-0.229881*** (0.051093)	-1.152664 (0.735587)	-0.368228*** (0.113420)
vt	0.058936+ (0.031885)	0.051656* (0.026244)	0.005161 (0.015544)	0.004402 (0.024813)	0.010983 (0.018555)
cp	0.057101*** (0.015937)				
(Intercept)				18.80759+ (11.00275)	7.632837** (2.514675)
R ²	0.30157	0.079928	0.55607	0.7369	
Adj. R ²	0.27651	0.071387	0.49529		
Num. obs.	758	758	741	665	741 (60 instr.)

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, + $p < 0.1$

Table 4.4: Model 1 to 5 for regression 2 sample g5

	Model 1	Model 2	Model 3	Model 4	Model 5
lag(gl1)			0.532816*** (0.052501)	0.433037** (0.147512)	0.719337*** (0.067168)
rr	-0.002760*** (0.000613)	-0.003804*** (0.000917)	-0.002221** (0.000736)	-0.002127 (0.002308)	-0.00263** (0.000885)
gl2	0.151365*** (0.028615)	0.146660*** (0.027039)	0.114022** (0.035822)	0.213185* (0.085649)	-0.06998 (0.099765)
gl4	0.218079*** (0.058385)	0.217751** (0.066030)	0.065287 (0.056315)	0.246841+ (0.146719)	0.056234 (0.039923)
vt	0.000104 (0.000220)	0.000046 (0.000213)	-0.000090 (0.000143)	-0.000132 (0.000719)	0.000145 (0.000191)
(Intercept)				0.0642978 (0.112802)	0.148112* (0.072559)
R ²	0.062421	0.065685	0.35147	0.5789	
Adj. R ²	0.057721	0.059271	0.3144		
Num. obs.	850	850	768	696	768 (60 instr.)

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, + $p < 0.1$

Table 4.5: Model 1 to 5 for regression 1 sample g2

	Model 1	Model 2	Model 3	Model 4	Model 5
lag(rr)			0.720756*** (0.093483)	0.781939*** (0.076679)	0.898921*** (0.040367)
gl1	-1.697171* (0.738220)	-1.581927* (0.676446)	-0.419481 (0.549111)	-2.803414 (2.19881)	-1.856415+ (1.077331)
gl4	2.940787* (1.340090)	1.670589 (1.111332)	1.121629 (0.859070)	2.811513 (3.241469)	0.773054 (0.496421)
gg	0.217883*** (0.061040)	0.126296** (0.041929)	0.049594 (0.034804)	0.037065 (0.080299)	0.019953 (0.037178)
man	-0.382620*** (0.071831)	-0.384044*** (0.066883)	-0.162603*** (0.038208)	-0.618179** (0.202388)	-0.089806** (0.033959)
vt	0.057664* (0.026156)	0.051513* (0.022777)	0.003934 (0.014682)	0.002273 (0.020212)	0.005505 (0.010669)
cp	0.036247*** (0.009500)				
(Intercept)				11.53158** (3.73364)	3.313186*** (0.921842)
R ²	0.23269	0.061941	0.53212	0.8565	
Adj. R ²	0.21452	0.056226	0.48191		
Num. obs.	1268	1268	1240	1114	1240 (80 instr.)

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, + $p < 0.1$

Table 4.6: Model 1 to 5 for regression 2 sample g2

	Model 1	Model 2	Model 3	Model 4	Model 5
lag(gl1)			0.521562*** (0.044445)	0.37969** (0.120070)	0.680947*** (0.093004)
rr	-0.002543*** (0.000560)	-0.002553*** (0.000647)	-0.001668*** (0.000482)	-0.00186 (0.001972)	-0.002810** (0.001018)
gl2	0.181595*** (0.031173)	0.181905*** (0.031210)	0.110704*** (0.032099)	0.203833* (0.085248)	0.062188 (0.084273)
gl4	0.157758*** (0.045529)	0.165791** (0.050440)	0.055593 (0.043353)	0.271278* (0.121174)	0.095687* (0.044393)
vt	-0.000134 (0.000205)	-0.000120 (0.000238)	-0.000162 (0.000167)	-0.000203 (0.000753)	-0.000502 (0.000799)
(Intercept)				0.102735 (0.096604)	0.218135** (0.077940)
R ²	0.057464	0.057253	0.32573	0.5225	
Adj. R ²	0.053324	0.052344	0.29541		
Num. obs.	1388	1388	1257	1139	1257 (81 instr.)

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, + $p < 0.1$

Table 4.7: Evolution of values between g5 and g2 for regression 1

Sample and model	lag(rr)	gl1	gl4	gg	man	vt	cp
Model 1 g5	N/A	-3.35**	3.97*	0.28***	-0.48***	0.05 ⁺	0.05***
Model 1 g2	N/A	-1.69*	2.94*	0.21***	-0.38***	0.05*	0.03***
Model 2 g5	N/A	-4.11***	1.55	0.12*	-0.49***	0.05*	N/A
Model 2 g2	N/A	-1.58*	1.67	0.12**	-0.38***	0.05*	N/A
Model 3 g5	0.73***	-1.82*	1.68	0.07	-0.22***	0.005	N/A
Model 3 g2	0.72***	-0.41	1.12	0.04	-0.16***	0.003	N/A
Model 4 g5	0.76***	-3.95	4.38	0.09	-1.15	0.004	N/A
Model 4 g2	0.78***	-2.80	2.81	0.03	-0.61**	0.002	N/A
Model 5 g5	0.74***	-4.82*	10.93**	0.12 ⁺	-0.36***	0.01	N/A
Model 5 g2	0.89***	-1.85 ⁺	0.77	0.01	-0.08**	0.005	N/A

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, ⁺ $p < 0.1$

Table 4.8: Evolution of values between g5 and g2 for regression 2

Sample and model	lag(gl1)	rr	gl2	gl4	vt
Model 1 g5	N/A	-0.002***	0.15***	0.21***	0.0001
Model 1 g2	N/A	-0.002***	0.18***	0.15***	-0.0001
Model 2 g5	N/A	-0.003***	0.14***	0.21**	0.00004
Model 2 g2	N/A	-0.002***	0.18***	0.16**	-0.0001
Model 3 g5	0.53***	-0.002**	0.11**	0.06	-0.00009
Model 3 g2	0.52***	-0.001***	0.11***	0.05	-0.0001
Model 4 g5	0.43**	-0.002	0.21*	0.24 ⁺	-0.0001
Model 4 g2	0.37**	-0.001	0.20*	0.27*	-0.0002
Model 5 g5	0.71***	-0.002**	-0.06	0.05	0.0001
Model 5 g2	0.68***	-0.002**	-0.06	0.09*	-0.0005

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, ⁺ $p < 0.1$

II.5 Discussion and possible extensions

We start the discussion with two summary tables with the coefficients for both regressions in the two samples:

Our sample suffers from a missing observations bias, in the very category we would like to investigate: resource rich economies. Missing observations on trade flows are concentrated at the beginning of the period, so that missing observations are more likely to be on the first quadrant of figure 4.8.

The first observation is that regressions one and two yield reasonably good fit considering the very aggregate nature of the data. For both samples, regression 4.43 gets an adjusted R^2 around 50%, a decent score considering the number of potentially missing variables. Regression 4.44 performs less well for sample $g5$ (31%) but similarly for sample $g2$. Autocorrelation tests for model 5 performed following Arellano and Bond (1991) rejects autocorrelation in the model at 5% for regression 4.43 and at 0.1% for regression 4.44. We can reject the hypothesis that missing variables (especially institutional variables in regression 4.43) are driving the results.

Diving deeper on variable significance, both regressions show the critical importance of the

lagged variable, which indicates the strong inertia associated with both the share of natural resource rents in GDP and the structure of exports in natural resource intensive raw materials. Resource dependence and export structure in raw materials are clearly better predicted by the previous year value. Lagged variables in both regressions 4.43 and 4.44 become more significant as autocorrelation is better controlled. The coefficient associated with the lagged share of natural resource rent is surprisingly larger in sample $g2$ than in sample $g5$.

We interpret this as evidence that resources rich countries are more heterogeneous as a group (within resources rich economies) with respect to the resources scarce economies (between the two groups). This interpretation is backed by the importance of clustering and cross-sectional dependence in both samples. The idea that there are several ways to be resource rich with respect to more similar resource poor countries is also consistent with the scenarios we presented in the section above. The relationship between the Grubel-Lloyd index for raw materials and its lagged value is weaker in sample $g2$ than in sample $g5$. This suggests the inertia in the value of the index is somewhat weaker in resource poor economies.

Moving to the Grubel-Lloyd for raw materials index in regression 4.43, the variable is statistically significant in most models. It is however harder to see in the context of persistent autocorrelation up to model 5. Variable $gl1$ is negatively correlated with resource abundance, with higher magnitude in sample $g5$ than in sample $g2$. Resource abundant countries are therefore more likely to experience one way trade in raw materials. The stark difference between the two samples suggests that this relationship is especially strong as resource abundance increases. This result is confirmed by the strongly significant, although of small magnitude, negative relationship between $gl1$ and resource abundance in regression 4.44. We consider that our hypothesis, a correlation between one way trade in raw materials and resource abundance is validated by these results.

The next significant insight pleading for the overall robustness of our results comes from the share of manufacturing in regression 4.44. The variable is systematically significant (control model 4 aside) and systematically negative. Resource abundance is clearly an impediment for the development of the manufacturing sector. The effect is again stronger in sample $g5$ than in sample $g2$. Once this is controlled for, we find the growth rate of GDP to be positively associated with resource abundance (when significant) as in Papyrakis and Gerlagh (2004). We therefore agree with the conclusion that it is not so much the GDP growth rate that is negatively correlated with resource abundance but the development of a competitive manufacturing sector. The observed possibility of growth subsidised by unsustainable use of natural resources is confirmed by our results in regression 4.43.

This result helps in making sense of the possible positive relationship between the Grubel-

Lloyd indexes for raw materials and intermediate goods. Two-way trade in raw materials is associated with two-way trade in intermediate goods since both are the consequences of a diversified production, more likely to be found in resource scarce economies. Although obviously tentative, we can hint at a confirmation using the lower values in sample *g2* for models 1, 2, 3 and 4. These results are nonetheless contingent to uncontrolled autocorrelation and should be considered with extreme care. Indeed, The Grubel-Lloyd index for intermediate goods is not significant in model 5 for both samples.

We controlled for inter-industry trade using the Grubel-Lloyd index for capital goods. The variable is not statistically significant in model 5 for sample *g5*, but is positively correlated with the dependent variable in regression 4.44. It is on the contrary not significant in sample *g2* in regression 4.43, and positively correlated with the dependent variable. The result in regression 4.44 mimics variable *gl2* in line with our hypothesis. Countries engaging in one way trade in raw materials tend to trade capital goods on an inter-industrial basis as well. The results from regression 4.43 are more puzzling, as they suggest that resource abundance is correlated with two ways trade in capital good, once the negative impact on overall manufacturing production is controlled for.

We are inclined to take this result coming from model 5 sample *g5* with great caution, as the coefficient value is clearly at odds with the other models. The size of the coefficient could be the result of unobserved autocorrelation. The positive sign seems to be observed across all models nonetheless, and constitutes a contradictory result which requires an explanation. This most likely comes from the composition of the bundle, which includes capital goods from the first transformation of raw materials such as refined oil or steel. This first transformation is often performed in the country of origin for ease of transportation. In that case, resource abundance could lead to an increase in two ways trade in capital goods, as greater volumes of steel are traded against machine tools for example.

Finally, the volume of trade is small in magnitude and of no statistical significance in either model 3, 4 or 5 for both samples and both regressions. We can therefore conclude that overall productivity gains did not influence the pattern of trade or that these effects have been captured by the time fixed effects. As for the evolution of world prices in natural resources, it was efficiently controlled for by the time fixed effects in lieu of the price index variable *cp*.

The results we present here are to be considered with caution, considering the high level of aggregation in the data and the unbalance in both samples. Numerous observations are missing about trade flows in natural resource abundant countries. Missing observations on trade flows are concentrated at the beginning of the period (as robustness tests below show), so that missing observations are more likely to be on the first quadrant of figure 4.8. Nevertheless,

our results appear robust enough to validate our hypothesis.

Resources abundant countries exhibit higher reliance on one-way trade in raw materials and a lower share of manufacturing in total value added. One-way trade in resources appears to be correlated with one-way trade in intermediate goods (and possibly capital goods). This indicates that structural change is associated with an overall diversification in exports across *all* the range of production goods. Therefore, countries characterised by low values for the Grubel-Lloyd index in raw materials tend to persist in reliance on natural capital and natural capital export as engines of growth, *de facto* postponing structural change (hence going through quadrant 2).

We even find evidence of a positive relationship between resource abundance and growth once this lack of structural change is controlled for. We can therefore further the claim that the resource curse manifests itself much more through a lack of diversification in both exports and production (with reliance on natural capital) than a slower GDP growth rate, which can be obtained through unsustainable exhaustion of natural capital.

Should further tests confirm these preliminary results, we should consider the pattern of trade and the exclusive institutional arrangement of resource abundant countries as two sides of the same coin. International trade in the context of the resource curse is usually studied as the trigger for an eviction effect from manufacturing to the resource intensive sector as in the Dutch disease, or as a vehicle for capital gains. Our results suggest that a significant impact of the pattern of trade survives the control for world commodities prices and that the impact of trade goes beyond the inter-sectoral shift of resources.

The indicator that should matter is the diversification of exports in all sectors, natural capital intensive goods especially. In this respect, institutional and trade patterns truly intertwine in that a diversified range of exports is harder to be captured institutionally, while institutional exclusiveness is harder to be preserved or created when imports and exports are more diversified. Investigating further this question could provide interesting insights on the merits of export-led growth in general, as opposed to the natural resource intensive exports led growth we just discussed.

II.6 Robustness tests

We present the results of three static and one dynamic panel models. We use the first three models as an indication of the potential biases in our results. Following Roodman (2009b) we

also provide in the tables the results of the two stages least square instrumental regressions, as a test for the dynamic panel bias and the likely convergence of our estimators. We controlled for cross-sectional dependence, autocorrelation and heteroskedasticity in all models and treated it using standard practices. The potential issues left are either related to the unbalanced structure of the panel, data collection issues or dimensionality issues (between the time T and number of individuals N).

Our dataset is unbalanced as observations are missing in some countries. These missing observations are not uniformly distributed across individuals and periods. Missing data are concentrated at the beginning of the period and in developing countries. Unfortunately, those happen to be our individuals of interest as most resource rich countries are developing countries. Most panel data analysis is conducted in a “small T big N” setting, with few periods but many individuals. Our estimations do not fall in this category as our time frame is quite long. This could be a problem as the notion of “fixed effects” is potentially dubious here. The implicit assumption behind our modelling strategy is that functional relations were stable in those countries for 20 years, which is unlikely.

As a result, we insist in this section on the stability of the relationships we presented in tables 4.3 to 4.6. To address those potential concerns over stability, we split both samples into two sub-samples of ten years each. We then follow the exact same modelling strategy applied on those four sub-samples. We notably keep the same instrumental strategy in the dynamic panel regressions, even though changes may be warranted. Results are available in appendix J.

Over the period 1992 to 2002 the results for sample $g2$ are quite stable for both regressions. The main relations, between resource abundance and the variables $gl1$ and man in regression 1 and $gl1$ and resource abundance in regression 2 are preserved. Results are more disappointing for sample $g5$ where the relation between $gl1$ and resource abundance still holds in regression 2, but regression 1 lost all statistical significance. As for the period 2002 to 2011, the relationship between $gl1$ and resource abundance only holds for sample $g2$ regression 2. For this period, the lagged variables in both regressions for the 2 samples seem to absorb almost all of the statistical significance yielded by the model.

Those results for the second half of the sample are disappointing. Still, they can be explained using a powerful underlying movement in our results. The period 2002-2011 is a period of rapidly increasing then decreasing natural resource prices (see figure 4.6). We observe this clearly in the yearly fixed effect in sample $g5$. As all the variables lose statistical significance, all the yearly fixed effects become significant with important magnitudes. Unsurprisingly, natural resource rich countries are greatly influenced by resource prices. Resource prices are confirmed to be a structural variable in resource abundant countries, shaping the current account and the

development of manufacturing.

Those results vindicate *a posteriori* our choice to present results over twenty years. The fact that resource abundance still pulls countries toward inter-industry trade in regression 2 for country 2 is proof that the relation exist even over the 2002-2011 decade. It is simply less potent or volatile than resources prices, so that its impact fades with strong variations in resources prices. The same can be said for manufacturing which regains briefly significance in regression 1 for sample g2. We can therefore conclude from those tests that resources rich countries behave differently when exposed to rapidly increasing resources prices. This is well-known problem when studying resource abundance. Unfortunately, we do not seem to have been able to neutralise that effect. This was expectable considering the results of the Arellano-Bond tests for regression 1 for the full samples.

A natural solution to this problem would be to use another instrument, that is less correlated with resources prices. On the basis of those first results, we believe that a small theoretical model could help us identify a better proxy. An alternative (or a complement) for this turn back to theory, would be to change our testing strategy. A natural alternative would be to use a simultaneous equation model (SEM) to test both equations simultaneously. SEM models are normally saved for the estimation of structural model. Despite this, they are increasingly used to estimate non-structural equations with common variables.

Our results underline again the inter-temporal trade-off associated with the gains from trade. When entering free-trade, countries have every incentive to increase specialisation of both production and the content of trade. These incentives are empirically balanced with forces of diversification from the versatility of instruments of wealth available in the domestic economy. This leads many advanced economies to the somewhat antinomic “diversification of exports specialisation”. The optimal transition from quadrant 1 to quadrant 4 in figure 4.8 should be skilfully timed to use the early gains from specialisation to favour innovation, the development of other instruments of wealth which will bring diversification.

The next logical step would be to determine to which extent this rebalancing happens endogenously through market forces and institutional incentives. Failure to follow the Hartwick rule and the results from chapter 3 would suggest that careful management of market forces is required as market mechanisms cannot distinguish between different sources for the gains from trade. It should be noted that these observations are independent from the role of economies of scale we discussed at the beginning of this chapter. Taking those into account only adds to the risks and resulting need for management as economies of scale are externalities from a price formation perspective.

This management is especially important when one considers that despite the important increase in commodity prices (see figure 4.6) patterns of trade still exhibit a high degree of inertia. This result needs to be confirmed with a more detailed analysis. But as things stand, a sustainable outcome for structural change seems to depend much more on policy than market forces alone. The question gets us to the difference between extensive and intensive margin. Increased reliance on the intensive margin could be a bad omen for future sustainability.

We hoped to convince the reader of the interdependence of trade incentives and institutional arrangements in creating a resource curse. We have so far established the role of trade patterns in a context of resource abundance. In the final part of this chapter we would like to delve into the institutional side of the coin. Doing so, we would like to stress the merits of using counterfactual scenarios in sustainability analysis. In the next section, we propose to examine domestic reinvestment of natural resource rents in the former socialist economies of Eastern Europe, with a focus on the Russian federation. To do this, we use the counterfactual method proposed by [Hamilton et al. \(2006\)](#) to estimate the lack of reinvestment in produced capital as advocated in the Hartwick rule. We then conclude on the respective importance of institutional and trade factors in creating a resource curse.⁸

III Empirical sustainability: The case of Russia

In chapter 3 we showed the importance of trade in establishing interdependence in development paths.

In the beginning of this chapter, we stressed how via the global supply chain, some countries would enter international trade in a fashion that could at least require additional savings in a sustainability setting. We went on to discuss the empirical findings on the particular case of natural resources abundant countries. We concluded on the impossibility to disentangle mostly domestic institutional responsibility from international trade induced patterns of production in explaining the peculiar behaviours of resource-rich countries. To back this claim we presented the roles of the direct and indirect impact of trade, discussing how they would play on institutional arrangement and most likely encourage extractive economic institutions. We then proposed quantitative evidence on the role played by resource abundance in dampening two ways trade in raw materials, de facto putting resource abundant countries on a less sustainable development path.

8. Which we would now define as taking an unsustainable path for structural change.

As was repeatedly stressed in this chapter and in earlier chapters, the key to better resource management and more sustainable development lies in the understanding of interactions between institutional evolutions and trade flows. This is the “open economy version” of the claim made in Arrow et al. (2010). This comprehensive model is beyond the scope of this chapter. However, we would like to propose as a first step to achieve this an empirical illustration based on a natural experiment. Natural experiments are highly desirable as they ideally allow to disentangle two or more potential effects. They are nonetheless, as any empiricist would know, reasonably rare and do not necessarily provide clear cut answers.

A natural experiment to test for the relative importance of institutional and trade factors for resource rich economies would require regions to be under a common institutional setting. Then those regions should break-up from the common institutional setting and form new entities asymmetric in resource abundance. Then, tracking the development paths of those regions, one could observe whether paths remain similar across regions (from the common institutional background) or differ between groups of regions depending on resource abundance. In the first case, institutional inertia is likely to determine natural resources management while in the second case trade-induced wealth allocation creates divergence between resource abundant regions and non resource abundant ones. The effect could then be controlled for using a group of natural resources abundant regions and a group of natural resources scarce regions reasonably similar from an institutional perspective.

Such a natural experiment is obviously hard to find. However, we believe that the break-up of the Soviet Union and the dismantlement of the communist block provides us with such an experiment. The former Soviet Union was institutionally homogeneous (Kornai 1992) and we can observe discrepancies in natural resources endowments between the newly constituted independent states. We also have with the former European members of the COMECON⁹, a potential control group as those countries were reasonably close to the soviet political and economic institutional setting before the break-up started in 1989. Those countries all have low rents from natural resources. As any natural experiment, this one is far from perfect, especially in terms of institutional similarities.

A whole literature is dedicated to the analysis of the transition of former communist economies (see for example the journals *Communist and Post-Communist Studies*, *Post-Communist Economies*) stressing the diversity of their experiences. Still, we believe this experiment is one of the most appropriate available to us¹⁰.

9. The Council for Mutual Economic Assistance.

10. One can speculate that an homogeneous democratic transition in the middle east during the Arab spring could have been a similar natural experiment. The actual dismal state of institutional change in the region stresses that natural experiments like the one we are looking for are hard to come by. Also, the very fact that

Inside the group of former soviet republics we focus on the Russian Federation. This is a natural choice as Russia is both the largest of the former republics and resource abundant. Russia is also interesting because it is less mentioned than other countries such as Nigerian, Saudi Arabia or Venezuela in the literature on the resource curse. There are instead many articles focusing on the consequences of rent-seeking behaviours in Russia, while it seems uncertain that Russia has fallen to the resource curse (Dülger et al. 2013).

One reason for this could be precisely that the Russian case is perceived as atypical from an institutional perspective. As we will see, current economic and physical value indicators would not naturally associate Russia with its neighbours. Since the fall of the USSR, the Russian federation undergone a transition from soviet institutions towards free market economics and liberal democracy¹¹. In that context, the swift growth of the Russian Federation between the financial crisis of 1998 and the subprime crisis starting in summer 2008 has been particularly impressive. GDP and GDP per capita increased twofold in constant USD, while numerous development indicators like the HDI, the mortality or the natality rate improved.

During this decade, Russia moved from the uncertainty of the Eltsine government and the “first transition” (1991-1998), which ended with the financial crisis of 1998. In this context, a transition is defined as a structural change articulating an economic (from planning to free market economics) and a political (from democratic centralism to pluralism and representative democracy) dimension. The Eltsine years witnessed a recomposing of the political and economic elite (Kryshtanovskaya and White 2005). As Vladimir Putin¹² rose as head of state, a new decade started (1998-2008) where Russia re-emerged as a major power.

We consider that this period is associated with a change in the challenges to the development of Russia. As a consequence, we call this decade the “second transition”. On the political front, the second transition is characterised by the power grabbing of the “United Russia” party (Gel’man 2008), which slowly monopolised power without the authoritarianism of the soviet period (Bader 2011). On the economic front, another kind of concentration is observed. The Herfindhal-Hirschman index for exports went from 0.132 en 1998 à 0.363 en 2008¹³ as the economy grew more polarised. More importantly for the global projection of power, Russia returned to growth after the 1998 crisis and the devaluation of the rouble. But as economic growth returns, so do concerns regarding sustainability (Bobilev 2005).

the post-communist transition happened peacefully and in such a short period from East Germany to Tajikistan is a manifestation of the relatively greater homogeneity of the communist bloc.

11. We define liberal democracy as a political organisation characterised by elections based on popular sovereignty, aiming at providing and defending natural liberties. These natural liberties are understood as in the universal Declaration of Human Rights of 1948.

12. As head of government from 1999 and president of the Federation from 2000.

13. 0 indicates perfect dispersion and 1 perfect concentration. The index is provided by the UNCTAD.

While economic growth brought Russia closer to the more advanced economies, it still is an emerging country by many aspects: faster growth, widening inequalities, and a tense political situation¹⁴. Economic power is concentrated in the hands of the oligarchs, new patrons of the state capitalism¹⁵ now implemented in Russia. Russia is also plagued by a persistent imbalance of the current account¹⁶, once the impact of natural resources exports is subtracted. Considered together, these problems cast a long shadow on the sustainability of Russian development.

Development being in essence a holistic process, it is usually analysed using a dashboard of indicators. These indicators usually confuse the *ends* with the *means* of development (GDP growth, medical insurance and coverage, investment, etc.). Multicriteria approaches are more exhaustive, but it is harder to derive a clear message, let alone policy recommendation when indicators send mixed signals. How should we weight economic progress against a deficient political process or a shrinking population? We believe that beyond the assessment of the current state of Russian development, the sustainability of this development is at stake.

We focus on the second transition in Russia as the sustainability challenge can be observed then stripped of more traditional transition and development concerns as in the first transition. This is also the best period for the setting of the natural experiment, as the institutional drift from the soviet era is not yet too important, while enough time was left for market mechanism to reshape resource allocation. Finally, now that Vladimir Putin is back as head of state, the second transition gives us some indication about what to expect during his new term regarding the sustainability of development.

We stressed in chapter 1 the different dimensions of a sustainable development and the need to balance opportunity and equity in a framework organised under the subsidiarity principle. We use in this section data on comprehensive wealth and Adjusted Net Savings (ANS) (Pearce and Atkinson 1993) as the closest indicator to this perspective. Despite justified criticism regarding the perfect substitutability assumption and under-performance as a predictive tool in developed countries (Ferreira and Vincent 2005), ANS are best suited to assess the dynamics of a development path.

We use ANS to characterise the development path of Russia and put into perspective the institutional evolution of the country. We use the distinction between extractive and inclusive institutions brought forward by ? to characterise the evolution of the institutional path in Russia. We then provide simple dynamic comparisons based on ANS and a composite index to show

14. As shown by the demonstrations following Vladimir Putin's return at the presidency in 2011.

15. We consider capitalism in Russia as state capitalism as the general orientation of the economy, especially in strategic sectors, is defined in accordance to or under the instructions of the central government and its political allies.

16. 366.28 millions in deficit in 2008 according to the Central Bank of the Russian Federation.

how the Russian course of development takes from resource abundant country-characteristics, but is still most closely associated with the performance of institutional siblings.

We then put forward the analytical framework we considered to be the best suited to the study of transitional dynamics. We follow [Hamilton et al. \(2006\)](#) and the [World Bank \(2006\)](#) to compute a counterfactual profile of investment in produced capital for Russia. The counterfactual method is in our view particularly relevant as it allows the normative assessment, based on rigorously defined assumptions, of a development path. We follow the version in [Hamilton et al. \(2006\)](#) centred on the Hartwick rule and produced capital, but this is clearly only the first step of more sophisticated counterfactuals and scenarios. An obvious first extension in the context of this thesis would have been the consideration of overseas investment.

To do this, we still miss an open economy version of the model in [Hamilton et al. \(2006\)](#), which still evades us and would yield an “augmented open economy Hartwick rule”. Once such a rule is established, the extra savings from the model in chapter 3 could also be taken into account as they are themselves counterfactual in nature. Still, the “closed economy” method is a useful complement for ANS as two similar levels of ANS may come from different fundamentals. By stressing the shortcomings of the reinvestment policy and the cumulative effect of these shortcomings, the counterfactual method provides a comprehensive assessment of sustainable development.

We show that although Russia exhibits positive ANS for most of the second transition, reinvestment policy lagged behind the requirements of the Hartwick rule. Russia consumed some of the rent from natural resources, ending with a stock of produced capital per capita 26.7% below the counterfactual level from the Hartwick rule for 2008. We use a simple linear model to forecast the results of this trend in 2018. We conclude that the 1998-2008 then leads to a level of produced capital per capita almost 95% below the counterfactual. We then discuss the results before concluding.

III.1 Sustainability and the Russian economy: from development to sustainable development

The Russian Federation emerged from the communist area with a sclerotic economy, lagging behind western Europe in both consumer goods and new technologies. The first transition (1991-1998) was dedicated to the conversion from planning to free market economics and resulted in massive poverty and social issues (low birth rate, mortality, alcoholism). Russia could nonetheless use its educated workforce and resources to return to growth at the beginning of

the 21st century, only to find itself facing the sustainability challenge.

III.1.1 Institutions from development to sustainable development

The soviet economy was structurally organised towards catching-up since the first and second plans (1928-1938). The centralised structure of soviet planning turned the system sclerotic (Kornai 1992) under Leonid Brejnev (1964-1982). The final attempt from Mikhail Gorbachev to reform the economy and the society of the soviet union critically disorganised the planning system (Hobsbawm 1994) and led to the dislocation of the country. Just out of communism, the Russian Federation critically lagged behind its western neighbours.

The evolution of poverty in Russia is well-documented, with on average 16 publications per year between 1992 and 2006 (Lokshin 2009)¹⁷. Poverty declined quickly but did not disappear (Bertin and Clément 2008). Another indicator of social disaggregation is given by alcohol over consumption by males. This increased the imbalance in the male/female ratio in Russia and further reduced the natality rate which was already declining in the 1980's.

Corruption already existed in the soviet era as an adaptation mechanism to the constraints of planning. The Russian workforce was highly educated at the beginning of the first transition, but ill-adapted to the realities of a free market economy (Fan et al. 1999). Both factors resulted in a huge informal sector to cater for the subsistence of the poor and the elderly. The new wage structure increased the number of people in financial distress, starting with women, pensioners and older workers who where ill at ease with the new economic needs (Brainerd 1998). As a consequence, inequalities have been continuously on the rise since 1991. This is a common trend with the rest of the world, but it became more acute in Russia following the economic power grab of the public estates by the new elite¹⁸.

Still, current value development indicators show an improvement of the situation as the first transition ends (see table 4.9).

17. See also the special edition of the *Revue d'Études Comparatives Est-Ouest*, Vol 37, Issue 2.

18. Some of its members coming from the old *nomenklatura*.

Table 4.9: Development indicators in Russia

Russian Federation	Total population compared to 1991	Births per woman	Children mortality below 5 years of age per 1000	GDP per capita ¹⁹	share of the population living with less than 2 PPP USD per day	Share of income held by the richest 10%	CO ₂ Emissions ²⁰	Energy Intensity ²¹	Energy Intensity per 1000 USD of GDP ²²
1991	100	1.73	26.9	5386	N/A	N/A	14.35	871122	490
1998	98.83	1.24	23.2	3300	10.54	27.94	10.39	587949	546
2008	95.5	1.49	14	6649	0.08	33.5	12.08	688482	328

Source: The World Bank, *World Development Indicators (WDI)*²³

The income share of the poorest 20% went from 4.36% of income in 1993 to 6.04% in 2008 while the income share of the richest 20% went from 53.34% in 1993 to 48.93% in 2008. The data show a continuous demographic decline despite a rebound in the birth rate. After the free fall of the first transition, per capita income increases sharply and poverty falls from 1998 onwards. There is however evidence of a “squeezed middle” as the income share of the richest and to a lesser extent poorest parts of the population increases faster than the middle class. As the economic contraction ends in 1999, gross investment peaks up (figure 4.13) after declining since 1991. The massive manufacturing contraction of the first transition resulted in lower CO₂ emissions and energy intensity. As a consequence, the second transition comes with a surge in CO₂ emissions. A positive signal is the fall in energy intensity per 1000 dollars of GDP, sign of productivity investment and the tertiarisation of the economy.

19. constant 2005 USD

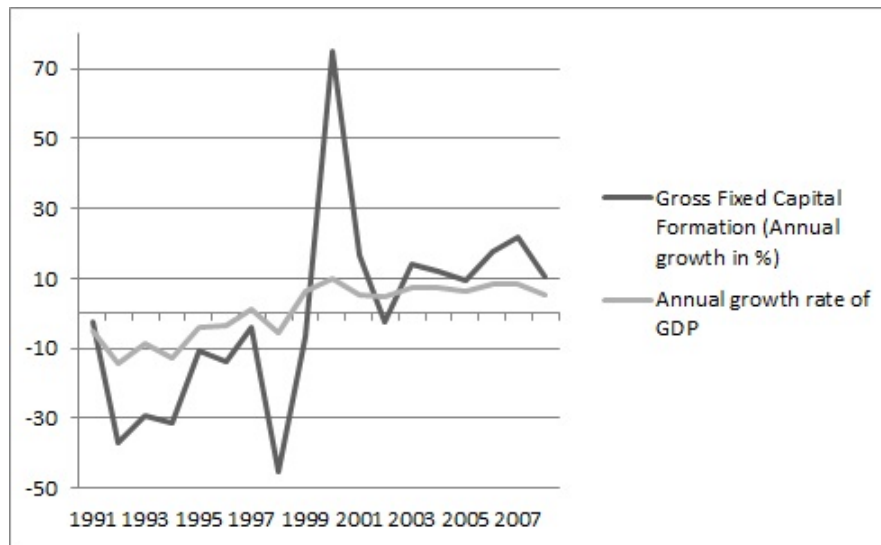
20. metric tons per capita

21. kt of oil equivalent

22. kt of oil equivalent, 2005 PPP dollars

23. Years 1991 and 1998 are missing for some indicators and are then replaced by the following year.

Figure 4.13: Gross investment and GDP growth



Source: *The World Bank, World Development Indicators (WDI)*

These figures deserve some political perspective. As the first transition unfolds, networks of influence are constituted to take control of the Russian manufacturing and energy production. First aimed at subsistence, these networks rapidly become the tools of supervision for the new ruling elite (Levin and Satarov 2000)²⁴. Vladimir Putin's election is a form of continuity with the soviet area as far as the role of the State for the society is concerned (Shlapentokh 2001). Considering the structure of political power in Russia and the role of corruption as a political tool to control and regulate the economy (Shlapentokh 2013), we would like to offer some operational perspectives on Russian institutions.

We define as institution any accepted and partaken social structure designed to solve coordination problems or regulate a potentially conflictual interaction between individuals inside a given society (see chapter 1 section II.1). To understand how institutions interact with natural resources in Russia and analyse sustainable development during the second transition we use the categories from ?. The authors offer to differentiate between economic and political institutions and within these two categories, extractive and inclusive institutions. Political institutions such as political parties, parliaments, local assemblies are to be considered inclusive when they give to each and everyone the possibility to get involved in a social life, but also to exploit individual and collective opportunities of development.

Conversely, extractive institutions only aim at extracting and or transferring power and opportunities from the social corpus to a small group of individuals. The same goes for economic institutions. Exclusive economic institutions concentrate wealth and income in the hands of an

24. See also the investigation in *Books* magazine num. 27, (Postel-Vinay 2011).

Table 4.10: World Governance Indicators for Russia

Indicator	1996	1998	2008
Voice and Accountability	-0.29	-0.54	-0.84
Political Stability and Absence of Violence	-1.22	-1.11	-0.76
Government Effectiveness	-0.51	-0.76	-0.34
Regulatory Quality	-0.28	-0.44	-0.39
Rule of Law	-0.87	-0.96	-1.04
Control of Corruption	-1.02	-0.93	-1.04

Source: The World Bank, World Governance Indicators (WGI)

elite while inclusive institutions offer equal access to economic opportunities and a fair income to ensure sustenance. Kaufmann et al. (2010) offer 6 criteria to assess the quality of institutions in a given country: Voice and Accountability, Political Stability and Absence of Violence, Government Effectiveness, Regulatory Quality, Rule of Law and Control of Corruption. Performance for each dimension is represented by a score ranging from -2.5 to 2.5 , 2.5 being the best performance. Russian scores for years 1996, 1998 and 2008 are presented in table 4.10.

Russia polls quite badly on all 6 indicators, which stresses the extractive nature of institutions in the country. Progress in terms of government effectiveness and political stability has not been matched by a reduction of corruption while participation to the civic debate declines. Using these 6 indicators, we can get a clearer picture of the evolution of Russian institutions. The first transition is associated with the relative failure of market mechanisms to reorganise single handedly the Russian economy as the inclusive economic institutions needed for this are still missing.

On the contrary, political institutions are quite inclusive. Faced with the progressive grab of economic power by the first oligarchs, the government apparatus organises the political re-conquest of the economy, which in turns progressively narrows the political space, with the notable rise of the United Russia (Gel'man 2008). As political and economic power becomes more concentrated, the central administration is used to reorganise the economy on both political and economic grounds.

This organisation draws heavily on export revenues from the energy sector and pays for the development of the welfare state to shore up the squeezed middle (Cerami 2009) and consolidate the political power of the central government. It also promotes investment in state controlled industries to maintain the illusion of renewed economic dynamism and inclusiveness as the system in fact gets more and more extractive.

In this context, the second transition is not about the very real development observed in the first transition, it is about the sustainability of this development in a context of greater extractiveness of institutions and reliance on natural resources depletion. The natural resources rent is the privileged instrument for the Russian renewal both domestically and internationally. The rent is for example used to offer benefits to boost the birth rate. But even the sound use of this bonanza does not seem to be on the agenda. [Martinot \(1998\)](#) and [Korppoo and Korobova \(2012\)](#) investigated energy efficiency in the residential sector. They show that reforms in the organisation of the real estate market to promote energy efficiency never took place because of subsidised prices which destroyed the incentives.

[Locatelli \(2007\)](#) and [Locatelli and Rossiaud \(2011\)](#) study the institutional organisation of the oil industry and show that the central governance endeavours to retake direct or indirect control over the whole sector. [Kalyuzhnova and Nygaard \(2008\)](#) extend this institutional analysis to the broader topic of the management of the rent by the state with similar conclusions. [Reynolds and Kolodziej \(2007\)](#) show using time series data that resource richness tends to encourage the capture of rent by the central government. This argument is supported by [Rutland \(2008\)](#) who shows how the energy rent and corruption form a self-reinforcing vicious circle favouring the ruling oligarchy in Russia. These facts stress how a behaviour common to resource rich economies intersects with the institutional reality of a country in transition like Russia to favour extractiveness in both political and economic institutions.

[Bobylev \(2005\)](#) observes that energy intensity is positively associated with the weight of natural resources dependent sectors. based on this observation, he advocates a reform of the fiscal system to minimize the environmental impact of development, following the European lead. Natural resources rent management intersects with many economic, political and social issues. This is in line with the more general predictions in ? and confirms the extractive character of Russian institutions. Still, this orientation is not set in stone. The Russian potential in renewables is huge considering the diversity of landscapes and geography. Exploiting it remains conditional to the rivalry in use for those spaces, which brings us back to the institutional setting. [Tynkkynen \(2007\)](#) shows how the use of the Russian immensity for natural capital maintenance or plain extraction is too often mutually exclusive.

Russia is confronted to some usual catching-up countries issues, constantly on the verge of falling into the "middle income trap"²⁵. The institutional framework currently enforced in Russia was effective in the very fashion presented by ?. An effective re-centralisation of the political power led to the possibility of efficient extraction of the rent.

25. The middle income trap is the situation in which a developing country stalls in its development path and fails to catch-up with advanced economy. This phenomenon is usually explained by wage inflation, which then lowers productivity gains as the country loses international competitiveness.

To some extent, this situation can be paralleled with the great plans industrialising the country in the 1930's, without being able to foster innovation and growth in the long run²⁶. Russia cannot grow complacent extracting the rent from natural resources: it should also plan for sustainable investment. This strategy starts with inclusive political and economic institutions as guarantors for the optimal use of the resource²⁷.

The end of the first transition is characterised by the rise of extractive institutions. Controlling for the institutional setting in Russia matters to appreciate the tenants of natural resources rent management. Rent is defined as the difference between the marginal cost of extraction and the market price. Estimating the marginal cost is hard as this first requires a production function fitted for the considered resource. To overcome this issue, rents are usually approximated using the average cost of extraction, computed as total cost divided by quantities extracted²⁸.

What comes first when assessing the rent is actually institutions related issues. Who is in charge of extraction? Private or public sector firms? How is the rent used? Is it consumed or reinvested? To the benefit of the whole country, or mostly for a social or economic elite? In the context of extractive institutions, rent management can lead to the resource curse. The curse is associated with the grabbing of the rent by the elite controlling production (Van Der Ploeg 2011, p. 23), which implies that a large rent may lead to extractive institutions and then sustain them. A scenarios review is performed by Heal (2011). He shows persuasively the link between rent management and sustainability.

Russian rent data are summarised in figure 4.14. The larger share of the rent comes from the energy sector, mostly from natural gas and oil. We saw earlier on that the reorganisation of institutions surrounding natural resources leads to a concentration of wealth and a political use of the resource. This rent grabbing behaviour by an elite may lead to unsustainable development. The Russian government tried to address this with structural reforms, trying to rebalance economic development and diversify the instruments of wealth. The equilibrium between reliance on oil, gas, coal and wood exports and the need to reduce reliance on natural capital was searched but never found.

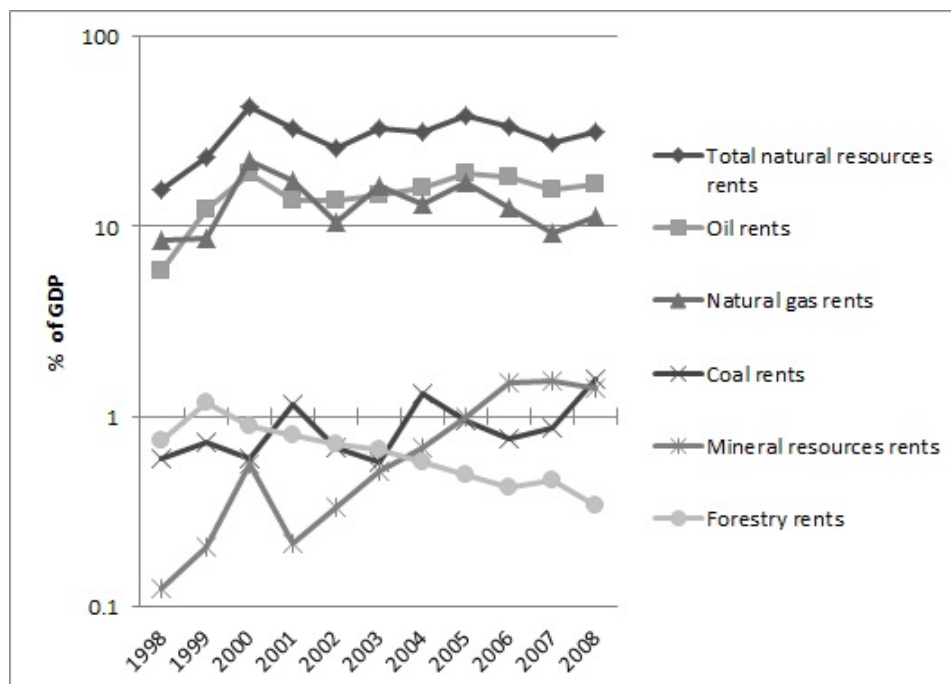
This is probably because those natural resources form the main revealed comparative advantage of the country (Chiappini 2011). Russia is still committed to an extensive development based on natural resources consumption, as the articles we presented clearly show. From this conclusion, our aim is to show that rent management cannot be considered in isolation of other issues but as the cornerstone of a sustainable development. It is by first presenting the

26. The parallels drawn by ? with China and Argentina appear especially telling here.

27. See also Yi-fu Lin (2012) on development strategies and natural resources management.

28. A complete presentation of the computation methods for rents is available in World Bank (2011).

Figure 4.14: Decomposition of natural resources rents in Russia



Source: *The World Bank, World Development Indicators (WDI)*

aims of sustainable development that the proper rent management tools can be defined and implemented.

III.1.2 1998-2008: Natural resources, institutions and development

Any development strategy aims at improving the human experience, the perceived quality of life. Sustainable development aims at improving the two major components of well-being: civil rights, political and socio-economic situation and access to desired goods and services. Allocation and continuous delivery of goods and services rest on resources available to society. Those resources ought to be managed optimally. It is finally critical that current and future generations each get a fair share of available resources to exert rights and fulfil responsibilities while satisfying their needs. Sustainability studies are dedicated to this last objective, studying the constraints on the means of a sustainable development. See chapter 1 for a detailed presentation.

Sustainability studies in Russia have been conducted mostly using multidimensional approaches. Shmelev (2011) proposes a dynamic picture of sustainability based on revealed Russian preferences embodied in a given set of indicators. Set against weak sustainability, he refuses to aggregate the multiple dimensions of sustainable development arguing of their incommensu-

rability. His work is based on a series of indexes (HDI, Education index, life expectancy, etc...) to embody the different goals and challenges to sustainability.

GDP per capita represents the economic pillar, CO₂ emissions the environmental pillar and life expectancy the social pillar. He then shows how Russian development is biased towards economic development (towards GDP per capita that is) and also in geographical terms as progress is concentrated in urban areas. [Bobylev \(2005\)](#) offers to take environmental degradation into account when assessing Russian development, using energy intensity indicators. He proposes to use taxation to amend people's incentives against preservation.

In these studies, Russia is also perceived as improving after the first transition, but still plagued by important spatial, economic, social and environmental imbalances. These findings are obtained from current value indicators and are therefore not suited to capture the intertemporal dimension of sustainable development (see chapter 1). Although it is clear that Russia is more developed in 2008 than in 1998, the price of development seems to be paid by natural capital and the rest of the environment. Can Adjusted Net Savings provide extra information on this conclusion? We use World Bank²⁹ data to obtain ANS series for the years 1998 to 2008, with all the relevant time series for the subcomponents used to compute it from Gross Savings. This gives us a profile over the decade for ANS and its subcomponents (figure 4.15).

The ANS average over the decade is 2.76%, while GDP increased 5.79% per year. This result is a first downplay for the Russian economic performance over the period as measured by regular economic indicators. ANS record the evolution of wealth and the ability of the country to sustain present and future development. GDP merely accounts for the income derived from production on a given year. As GDP growth rate outperforms ANS, the share of income allocated to consumption is set to rise. From this deduction, one can distinguish between three cases depending on respective GDP growth and ANS values:

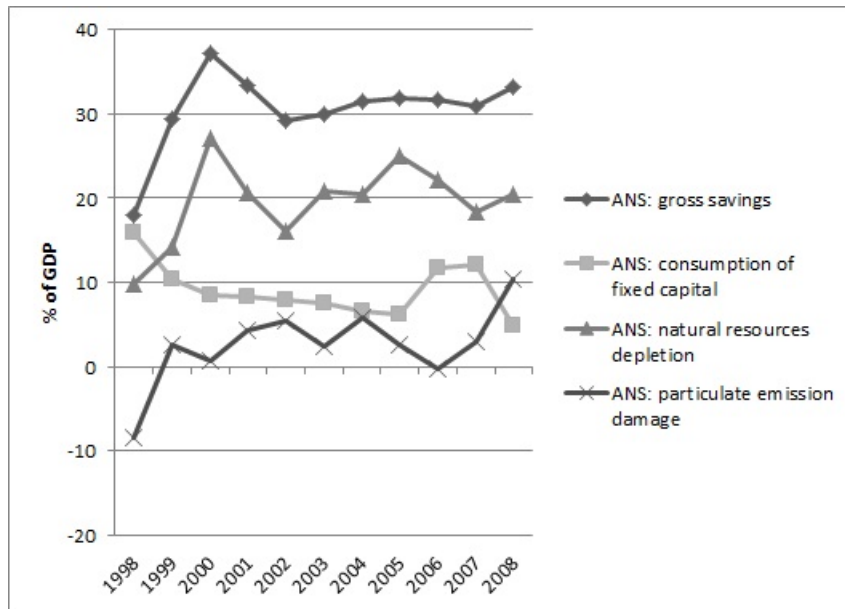
- If ANS growth rate as a percentage of GNI is negative, the country's development is unsustainable.
- If ANS growth rate as a percentage of GNI is positive but inferior to the growth rate of GDP, the country favours consumption over savings. It will therefore become unsustainable at some point.
- If ANS growth rate as a percentage of GNI is superior to the growth rate of GDP, the country raises the share of savings in income. It is therefore sustainable under the weak sustainability assumption.

These cases should be defined using the GNP instead of the GDP, but the difference is

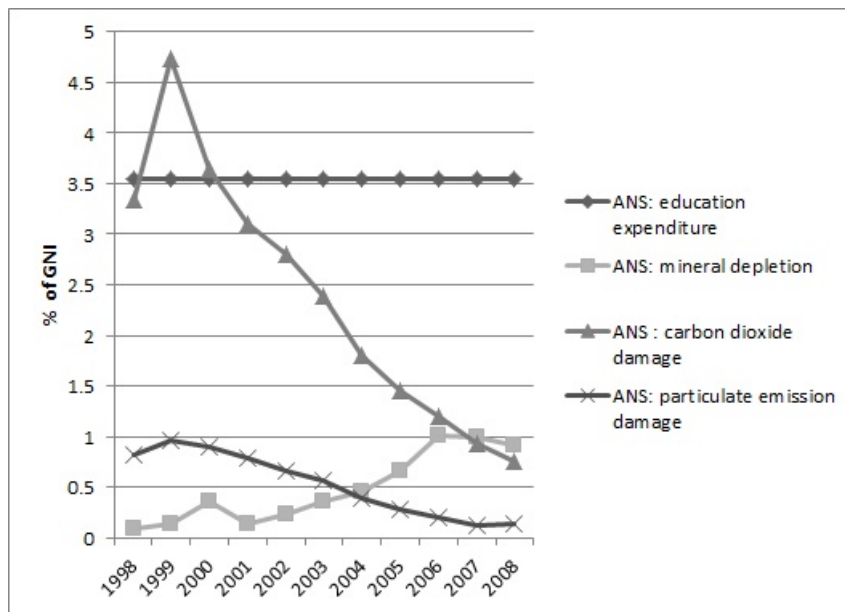
29. Data from the World bank Databank, World Development Indicators (WDI).

Figure 4.15: ANS and components in Russia

(a) ANS and main subcomponents



(b) Others subcomponents



Source: The World Bank, World Development Indicators (WDI)

minimal for relatively closed economies as a percentage of GDP. They are to be put in the perspective offered by [Hamilton and Hartwick \(2005\)](#) who link ANS to the produced capital return rate³⁰ and the investment rate.

In this model consumption increases when ANS growth is superior to the average market rate and falls when ANS growth is inferior to this same rate. As we lack any observable market rate, our empirical rule can be considered consistent with the theoretical prediction. Consumption is increasing in Russia, in a way that is detrimental to rent reinvestment following the Hartwick rule. These elements are important to put the raw ANS rate into perspective as ANS are based on an assumption of sustainable levels of consumption³¹. The indicator may therefore send a wrong signal of sustainability if consumption is *already* unsustainable or increasing rapidly. This is due to the way Comprehensive Wealth is estimated by the World Bank, using 25 years of consumption flows.

If GDP growth is superior to ANS growth Russia will deplete its natural capital even with a high rate of gross savings. This observation brings us back to the resource curse ([Sachs and Warner 1995](#)). Russia is not, *stricto sensu* falling into the resource curse during the second transition. ANS show here their crucial forward looking dimension: although Russia seems to be on a sustainable path now, future sustainability is in jeopardy based on current figures. This diagnosis is comforted by our observations on institutional extractiveness. It makes sense for rent grabbing to be associated with potential unsustainable management of resources. Intensive natural resources depletion clearly shows in ANS (see figure 4.14). The Pearson correlation between ANS and the natural resource depletion series is -0.33, suggesting a significant impact of natural resources on the final message of ANS.

ANS synthesise information from all the dimensions of sustainable development to produce a diagnosis of un-sustainability during the second transition in Russia. This is consistent with the observations in [Bobylev \(2005\)](#) and [Shmelev \(2011\)](#) based on multiple indicators. It should be noted that those studies used ANS, but only as a descriptive tool. We just illustrated the additional information from a comparison to GDP growth. ANS are also important in enabling international comparisons between countries as well as comparisons over time.

In the next section we would like to use this property and compare ANS between Russia and neighbour countries. Finally, using the counterfactual method in [Hamilton et al. \(2006\)](#)

30. This theoretical rate is the cost of produced capital. It is traditionally estimated using the real interest rate, the average rate used by banks adjusted for inflation. This rate is inferior to the growth rate of GDP for our period of study in Russia. This rate is however computed without taking into account natural resources depreciation, without even mentioning market inefficiencies in the Russian banking sector. The GDP growth rate seems to us the best proxy available.

31. See the [World Bank \(2011, p. 93\)](#).

we build a counterfactual investment profile for produced capital during the second transition. The results of this study gives the full scale of the lack of reinvestment in Russia. This diagnosis over time is a useful addition to the literature and makes the most of ANS.

III.2 Comparisons and counterfactual sustainability

We compare the ANS record in Russia with the record of countries with either institutional similarities or a similar levels of natural resources rents (as a percentage of GDP). We rank the countries in our sample using as a yardstick a composite index with geographical, demographical and institutional dimensions. Russia emerges from those comparisons as an outlier, institutionally closer to its neighbours than from the other resource abundant economies. We then present the counterfactual produced capital and show that Russia under performed during the second transition compared to the Hartwick rule. This finding leads us to the conclusion that to catch up on more advanced economies, whether former communist countries or western European, Russia has to change its resource management policy and engage in sustainable development.

III.2.1 International comparisons based on ANS

We stressed the importance of institutions in the management of the rent from natural resources. This relationship is characterised by two potential ways of causation. Either countries with extractive institutions systematically engage in suboptimal management of natural resources, or resource abundant countries systematically drift towards extractive institutions. The literature on the resource curse stresses (Van Der Ploeg 2011) similarities in resource rich countries, from the Dutch disease to the institutional setting. A first comparison of interest would allow us to investigate whether Russia is closer to resource rich economies or its neighbours from an institutional perspective. This is especially important here since the break-up of the former Soviet Union constitutes a natural experiment in this perspective.

Former Soviet Union republic used to share a common government and a relatively homogeneous institutional system, both politically and economically (Kornai 1992). We can then observe an objective heterogeneity inside this group: natural resource endowments. Those countries are therefore at the core of our comparisons. We then add countries similar to Russia in terms of our dimension of interest, natural resources abundance. Following the literature on the resource curse, those countries should register institutional similarities, but this is not controlled for in the selection process. Finally to control for institutional similarities in former

communist countries, we use as a control group the former members of the COMECON, all of them being relatively poorly endowed in natural resources.³² This gives us a total of 28 countries.

We then rank these countries using a composite index build from current value indicators. The index aggregates institutional and physical dimensions. The method of aggregation for the index is presented in appendix L. The index is based on the Borda ranking method as in Dasgupta (2001). We use four series: the transmission and distribution losses on the electricity network, population density, the share of natural resource rent in GDP and a composite index based on the variables presented in table 4.10. The decision to average the 6 dimensions into one was taken to keep the weight of the institutional dimension in par with the other variables.

Those four variables capture the physical dimension through resource abundance and electricity losses, the role of geography via population density and institutions. We use the index to rank our 28 countries and from the ranking we derive 5 groups depending on the average value for the index over the period.³³ The 28 countries, their group of origin and during the comparative exercise are listed in appendix K. Over a theoretical value between 1 and 28, the actual values taken by the index range between 5.95 and 25.77 on average. The index offers significant discrimination between the countries in the sample.

We use the observed break in the values to constitute our groups. The target group is the group including Russia, taking index values between 9.20 and 10.59. There are 6 countries in the group³⁴: Azerbaijan, Kazakhstan, Nigeria, Russia, Syria and Uzbekistan. Control group 1 has an index value ranging from 5.95 to 8.40. It is composed of three natural resource rich countries and Kyrgyzstan, former soviet republic also resource rich. Control group 2, with index values ranging from 12.04 to 14.09 is composed of 4 former soviet republics. Control group 3 (index values between 16.13 and 17.81) is the most heterogeneous with countries belonging to all three groups of origin. Group 4 (index values between 19.86 and 25.77) is composed of Bahrain, Lithuania and 4 former members of the COMECON.

The composite index yields an expectable ranking³⁵. Control group 1 takes the lion share of natural resources abundant countries. That makes it an interesting group to gauge the proximity between Russian characteristics and an archetypal resource abundant country. Control group 2 is composed of former soviet republics quite similar to Russia judging by their index ranking. This control group will be useful to assess the impact of institutional factors as these

32. Despite the diversity of cultures and institutions in these countries, similarities with the former soviet republic are important enough to use these countries as a control group (Lavigne 1985).

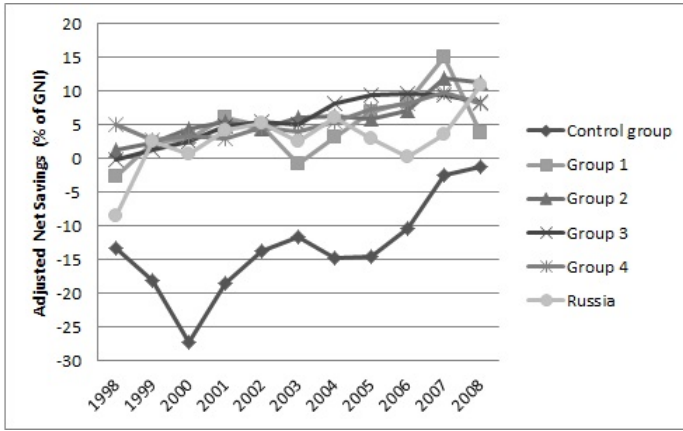
33. We can use the average value as the variance of the time series is relatively weak.

34. Average values and correlation coefficients for this group are subsequently computed excluding Russia.

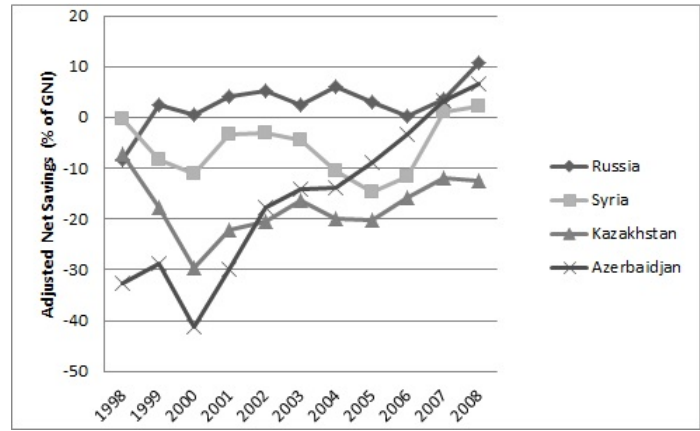
35. The full ranking is available in appendix L.

Figure 4.16: Adjusted Net Savings in Russia

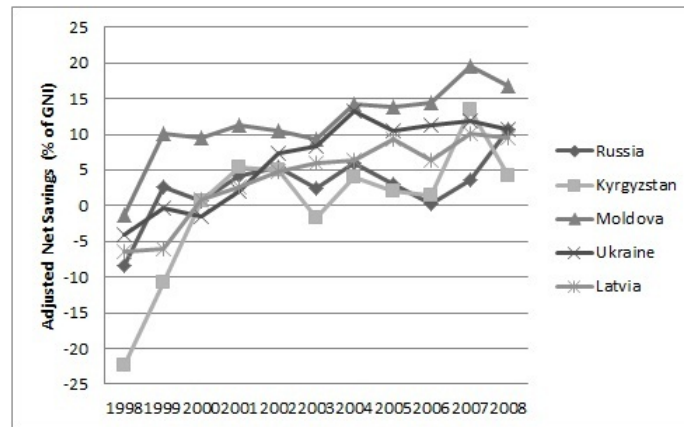
(a) ANS in Russia compared to the groups



(b) ANS in Russia and inside the target group



(c) ANS in Russia and in individually close countries



Source: Author's calculations from the World Development Indicators(WDI), the World Bank

countries are relatively less resource abundant than Russia. Control group 3 is composed of the former soviet republic that are quite far away from Russia in the ranking plus Bulgaria and Romania, usually considered as the less advanced transition economies of the former COMECON.

Control group 4 is composed of the highest ranking scores and confirms that the former COMECON drifted away from the former Soviet union quite rapidly after 1991. The group is composed of Lithuania, Bahrain and the rest of the majority of the former COMECON. These countries are densely populated with good institutional scores and relatively poor in terms of natural resources (with the exception of Bahrain, which comes out as an outlier here). The correlation between low institutional scores and resources abundance comes out quite strongly in the ranking from the composite index. We can now compare these groups with Russia in terms of ANS.

Table 4.11: Russia and the control groups

% of GNI	ANS	Natural capital depreciation	Net investment
Russia	2.76%	19.34%	11.56%
Target group	-13.28%	29.93%	8.90%
Control group 1	4.56%	18.52%	14.64%
Control group 2	6.05%	1.92%	14.35%
Control group 3	5.83%	1.27%	15.07%
Control group 4	5.61%	3.77%	12.33%

Average values between 1998 and 2008

Source: Author's calculations from the World Development Indicators(WDI), the World Bank

Figure 4.16 represents ANS in Russia compared to other countries in the sample. Russia seems closer to the average performance of groups other than the target group (see figure 4.16a). Figure 4.16b compares Russia with the other countries in its group. Russia outperforms its potential peers in 2007 and 2008, in Syria and Azerbaijan aside. Individually, countries that are actually correlated with Russia's values are in groups 1,2 and 3, not in the target group. The composite index and ANS produce a different message. ANS would place Russia closer to countries with a higher index score than countries in group 1.

This suggests that dimensions such as the density of population or climatic conditions play a weaker role in overall performance than institutional and economic factors. To put this first finding into perspective, we compare the average Russian performance in terms of ANS, natural capital depreciation and net investment with the control groups. By “de-constructing” ANS this way, we can identify the respective contributions of those dimensions to the final result (see table 4.11).

Comparisons in table 4.11 bring many insights. We have the confirmation that ANS in Russia are on average between the target group and group 1, although closer from group 1. The same is true for natural capital depreciation. The leading role of natural resources for Russian development finds confirmation here. This weights on ANS, so that Russia ends up behind all the control groups. When it comes to net investment, the result is the same, Russia ranks between the target group and group 1. This has probably much more to do with natural capital depreciation than gross investment as this last variable was actually quite dynamic over the decade (see figure 4.13).

This lower average for net investment brings Russia closer to group 4, which suggests that it is also linked to a more important stock of produced capital. Lower returns on a larger stock may justify lower net investment. A final potential explanation lies in the imbalances of the Russian financial account. Financial capital invested abroad is missing at home to raise

Table 4.12: Spearman correlation coefficients across groups and indicators

Groups/Russia	Net investment	Natural capital depreciation	ANS	GDP growth
Target group	0.718	0.754	0.090	0.336
Control group 1	0.372	0.645	0.309	0.536
Control group 2	0.336	0.863	0.445	0.409
Control group 3	0.581	-0.172	0.309	0.318
Control group 4	0.336	0.563	0.218	0.281

Source: Author's calculation from the World Development Indicators(WDI), the World Bank

the overall stock of produced capital (see section III.2.2). Considering average performance per group suggests that Russia, although investing in a way similar to its neighbour, manages natural resources just like other natural resources rich countries. This duality between regional institutional attachments and a common global attitude towards natural resources is the core of our study.

To discriminate between the impact of both allegiances in terms of sustainable development, we computed the Spearman correlation coefficients between Russia and the groups for ANS, natural capital depreciation and net investment. On net investment, while the average performance brought Russia closer to group 4, the correlation over time is stronger with the target group. This would indicate a natural resources induced synchronicity between investment cycles. Turning to natural capital depreciation, we observe high correlation between Russia and all the groups, group 3 excepted. This finding is the result of the method used to compute the rent, using the same world prices. This makes the negative correlation in group 3 an outlier, which can only be explained by the very low weight of the rent in those countries, coupled with a difference in the nature of the natural capital involved.

Correlation in ANS between Russia and the groups put group 2 as the most correlated with the Russian dynamic of development. This is for us the demonstration of the usefulness of ANS as a sustainable development indicator. Considering the sole value of rent as a share of GDP, Russia is better associated with other resource rich countries. But a comprehensive present value indicator like ANS captures the atypical position of Russia amongst those countries. The level of ANS in Russia is closer to the resource rich countries of group 1, but the evolution of the indicator as captured by the correlation coefficient brings the country closer to countries institutionally close such as those in group 2.

The composite index with which the target group is constructed gives an similar average ranking for countries that have strong discrepancies in individual characteristics. The sound theoretical basis of ANS correctly describes the common trends in development, as opposed

to current value indicators which only point at common characteristics at one point in time. Hence, members of the target group have a dissimilar ANS evolution compared to Russia³⁶ which can only come from under-weighted or unobserved factors which play a major role in natural resource rent management. ANS seem to better take these elements into account, which have to be institutional or institutions-related as their addition in ANS moves Russia closer to group 2.

ANS are based on a rigorous theoretical framework which captures through all the instruments of wealth the consequences of institutional inertia on development path. It cannot do so perfectly as institutions are not yet included in the indicator, but clearly does a better job than indexes based on current value indicators. These institutional impacts play a role on resource management and allocation, which ANS do take into account when physical variables cannot. We can test for the robustness of this observation comparing the correlation coefficients for ANS and GDP growth. The correlation coefficients are similar between Russia and control groups 2,3 and 4 for ANS and GDP growth. They diverge for the target group and control group 1.

ANS bring a more accurate picture by incorporating the impact of natural resources management in overall resource allocation, which indirectly integrates the weight of institutions in the equation. For countries having similar resource allocation institutions and little natural resources, the message from ANS and GDP growth is logically quite similar. It should be noted that a common base for development does not preclude cumulative divergence. Once the impact of natural resource management is accounted for, Russia is closer in terms of development path from countries that are geographically, culturally and institutionally close. ANS allow to monitor the intertwined challenges of development and sustainable development.

We studied the ranking of Russia with respect to potentially similar countries, whether in terms of institutional similarities conditioning development, or in terms of plain natural resource abundance. Both factors seems to be taken into account and correctly weighted by ANS. We show how institutional determinants, as described in the literature on the resource curse ([Van Der Ploeg 2011](#)), have a relatively stronger influence on the Russian development path. ANS rank Russia between the more advanced post-communist economies and resource rich countries subject to the resource curse.

It does not seem possible, even using more advanced quantitative tools to establish whether

36. This result should be considered tentatively as some countries in the target group are not taken into account in the comparisons (ANS data is missing). Results in table 4.11 suggest that those data would bring the target group closer to the control group 1, as countries like Nigeria or Uzbekistan obtained lower index scores than Russia.

Russia suffers from the resource curse or the Dutch disease (Dülger et al. 2013). To get an insight on this question, we propose to use the counterfactual method proposed by the World Bank (World Bank 2006) and Hamilton et al. (2006) to investigate in more details the rent reinvestment strategy. In the articles mentioned, Russia was not part of the sample considered.

III.2.2 The counterfactual study

Sustainability derives from the necessity of non declining consumption over time and can be assessed by indicators. As we saw in chapter 1, Adjusted Net Savings when computed correctly, indicate the rate of change in comprehensive wealth and therefore sustainability. This led to the introduction of the Hartwick rule (Hartwick 1977) as a guide for reinvestment in line with the maintenance and expansion of wealth. Negative genuine savings indicate un-sustainability, but this leaves open the question of excessive reinvestment. Even more to the point, there is the possibility for a country to invest without any attention for the depletion of its natural resources, but still in such quantities that adjusted net savings are positive.

The risk is that investment might fall below the minimum level of reinvestment of the rent in case of recession or structural shift towards more consumption. In this section we compute the 2009 level of produced capital in Russia, had reinvestment of the rent according to the Hartwick rule been implemented. The Hartwick rule is the standard reinvestment rule derived from the Solow (1974) model. Its limits are investigated in Asheim et al. (2003) and in chapter 1. Hamilton et al. (2006) present a modified Hartwick rule to account for unbounded consumption in the reinvestment in produced capital.

We would like to stress that the counterfactual method is in our view not only the natural complement of ANS, but also a necessary tool for policy design. Building reinvestment scenarios based on sustainability rules provides the rationale for policy intervention to correct asset misallocation. Based on our description on the workings of economic institutions, it seems unlikely that market mechanisms may correct incentives and investment strategies in resource rich economies. Building scenarios based on the Hartwick rule, the open economy Hartwick rule and the augmented open economy Hartwick rule will guide governments in using policy instruments to balance assets distribution and investment. The investments we propose here are only a first step towards those comprehensive scenarios, but the results are already telling.

We assume rents are invested only in produced capital. Would rents be invested in other forms of capital in Russia, we would naturally under-estimate the current level of investment in the country. Education expenses or pro-natalist policies could be forms of investment in human

Table 4.13: Comprehensive Investment in constant 2000 USD

Year	Comprehensive investment(I^g)
1998	-123 572 708 254
1999	-26 850 135 565
2000	-46 073 222 093
2001	-26 602 710 011
2002	-10 737 037 465
2003	-20 503 953 121
2004	-21 545 480 170
2005	-35 221 865 405
2006	-46 152 332 284
2007	-33 341 979 050
2008	-10 891 977 104

Source: Author's calculations from the World Development Indicators(WDI), the World Bank

capital, with a compounded effect as human capital is typically characterised by increasing returns. As a consequence the results we provide are to be considered as the lower bound of actual reinvestment. Still, as ANS data show that Russian investment in human capital has been stable as a percentage of GNI, it is unlikely that we are missing a fundamental effect. We build our study using data from the World Development Indicators, including ANS data. Following World Bank (2006) we define comprehensive investment as:

$$I^g = I - D - R \quad (4.45)$$

With I^g comprehensive investment, I investment in produced capital, D produced capital consumption and R natural resources consumption, that is the variation of the available stock S of natural capital. Comprehensive investment is actually negative for every year between 1998 and 2008. Russia consumed the equivalent of 270% of 2009 GNI in natural resources, faced 139% of the same 2009 GNI in produced capital depreciation and invested only 238% of 2009 GNI in produced capital. Comprehensive investment over the period represents a total loss in capital of 171% of 2009 GNI (in constant 2000 USD). Table 4.13 shows comprehensive investment per year.

Armed with these comprehensive investment flows, we can elaborate several scenarios.

Scenario 1 is our reference scenario. It represents regular net investment in produced capital.

Scenario 2 represents the investment profile following the standard Hartwick rule. In this scenario, investment in produced capital is divided into two subcomponents. First, there is investment to compensate for the depreciation of produced capital ($I = D$ using our notation). Second, investment of the entirety of the rent from natural resources into produced capital, so that total comprehensive investment is actually null: $I^g = D - D +$

Table 4.14: Produced capital endowments under the 4 scenarios

	Scenario 1, Produced capital per capita in 2008 (constant 2000 USD)	Scenario 2 compared to baseline scenario	Scenario 3 compared to baseline scenario	Scenario 4 compared to baseline scenario
Russia	18594	+15.2%	+27.6%	+24%

$R - R = 0$. Under this scenario ANS are also null.

Scenario 3 starts from scenario 1 and adds the Hartwick rule, that is observed net investment over the period plus the reinvestment of the entire rent into produced capital. This gives us $I^g = I - D + R - R = I - D$. This scenario is a combination of the first two.

Scenario 4 starts with the assumption that the highest level of gross investment observed over the period (the 2008 level that is) could have been reached every year. We compute comprehensive investment using this sole assumption, without explicit reinvestment of the rent so that Russia invests every period $I^g = I_{2008} - D - R$.

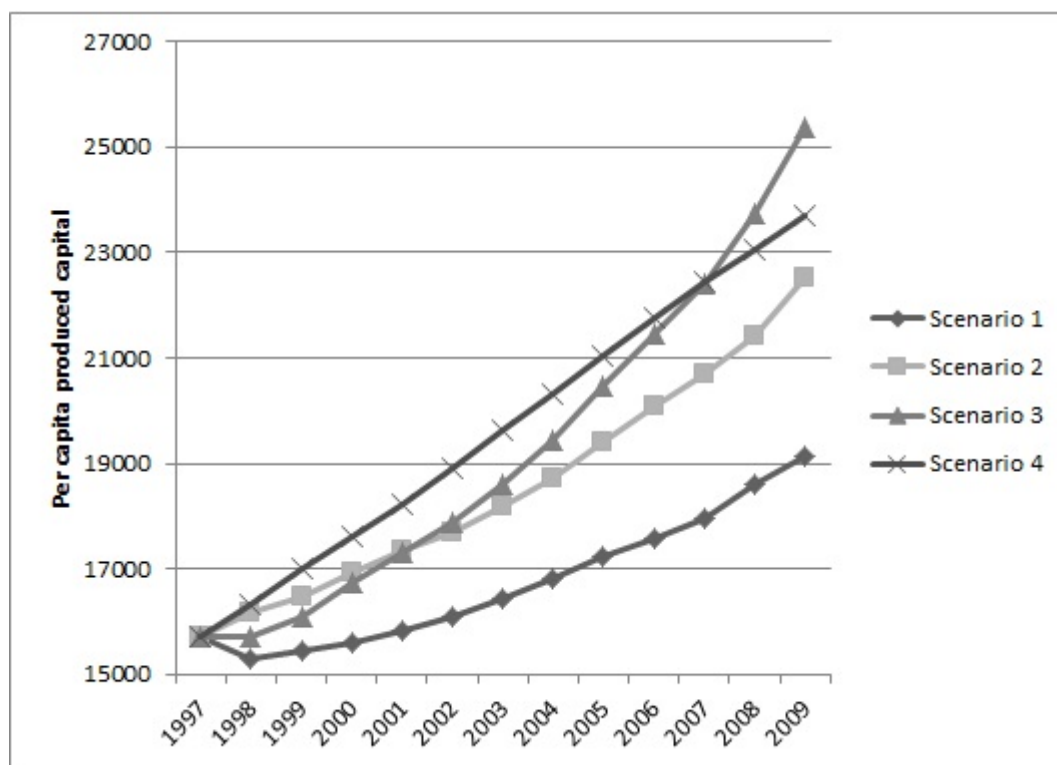
We use as a starting point the produced capital stock in 1998. We add to this stock the investment profile from the baseline scenario and the three counterfactual ones. Results are shown in table 4.14. The baseline scenario gives a 2008 produced capital stock of 18 594 2000 USD. Under scenario 4, the other scenario without explicit sustainability concerns, Russia gets a counterfactual stock 24% higher and a comprehensive wealth 15% higher.

Consider now the 2 scenarios incorporating the Hartwick rule. Scenario 2 corresponds to the standard Hartwick rule and yields a per capita produced capital stock 15.2% above the baseline. Scenario 3 tops the results with 27.6% above the baseline produced capital and comprehensive wealth 15.8% higher. Scenario 3 where observed behaviour is combined with the Hartwick rule helps us appreciate the failure of the current reinvestment policy. Russia could have had a produced capital per capita of 23 730 2000 USD in 2008, a level comparable to Poland under this scenario (see also figure 4.17).

These scenarios stress the cumulative consequences of natural capital depletion. We stressed that ANS are positive for most of the decade, but an early failure to follow the rule has lasting consequences as the capital that hasn't been build is missing to provide the income needed to increase and maintain capital in the period and so on. As this decade which witnessed in many aspects the come back of Russia on the international stage unfolded, the country failed to accumulate between 15 and 25% of the produced capital it should have built. This single figure gives a magnitude of the challenges associated with sustainability.

In a recent publication for the United Nations [Atkinson et al. \(2012\)](#) stress similar issues

Figure 4.17: Rent reinvestment scenarios



Source: Author's calculations from the World Development Indicators(WDI), the World Bank

in many emerging economies otherwise presented as role models during the last decade. China is of course the emblematic example, but India and Brazil are also failing reinvestment. Our scenarios do not model explicitly the price of commodities (Vincent et al. 1997) or the possibility to invest the rent abroad, via portfolio or direct investments (Van der Ploeg 2010). Here the fact that ANS are computed using GNI instead of GDP may play a role if the rent is invested abroad in structures that are not legally owned by Russians.

It is theoretically possible that Russian assets invested for example in Cyprus are equal or superior to the total amount of the rent. Still, we believe this possibility should not be considered in a counterfactual study on sustainable development, as those resources are in any case subtracted from domestic development to be dedicated to foreign development, in another spatial and legal area. Should those assets be invested back at a later date, they have already been missing for some previous capital accumulation periods and slowed down development. Our counterfactual study also stresses the need to maintain a steady flow of investment, at least equal to $D + R$. In the Russian case, the net impact would be negative in any case as FDI in Russia are inferior to Russian investments abroad.

The impact of reinvestment paths, is cumulative, and as such more important for longer

horizons. The study in [Hamilton et al. \(2006\)](#) is conducted over 30 years, between 1970 and 2000. Available ANS data do not allow us to replicate the study over the same interval. Nevertheless, considering the regularity of capital accumulation in the scenarios we presented, we can without adding too many extra assumptions complete our presentation with a little forecasting exercise. We apply a simple linear model on the capital accumulation series from 1997 to 2009, simply using the trend from the model. We then add produced capital to natural capital to obtain an estimate of comprehensive wealth (neglecting the contribution of other instruments of wealth). Results are presented in figure 4.18.

The twist in the series in 2008-2009 is simply the connection of the forecasted trend with computed values between 1997 and 2008. In 2018, accumulated produced capital in scenario 3 amounts to 30 269 per capita constant 2000 USD when in scenario 1 the total of natural capital *and* produced capital only amounts to 31 999 constant USD per capita³⁷. This amounts to 105% of produced capital only in scenario 3. Without any urgent and decisive action, Russia will consume by 2020 the equivalent of what should have been reinvested under the Hartwick rule from 1998.

If Russia reinvests the rent from natural resources into produced capital, under the assumption of perfect substitutability between different instruments of wealth, it could theoretically compensate its counterfactual wealth losses by 2008 and similarly by 2018. These striking figures should obviously be tempered by the exclusion of human capital from the comprehensive wealth estimates. This potential objection should be put into the perspective of the shrinking Russian population. Although a shrinking population requires less resources, it also accounts for less human capital. Population in Russia shrank by 3.3% between 1998 and 2008. One of the great legacies of the soviet period is the high level of education of the population, but it also leaves the country with little margin for qualitative improvements. One can therefore safely assume that Russia is also slowly eroding its human capital, which makes this instrument of wealth unlikely to contribute more to comprehensive wealth.

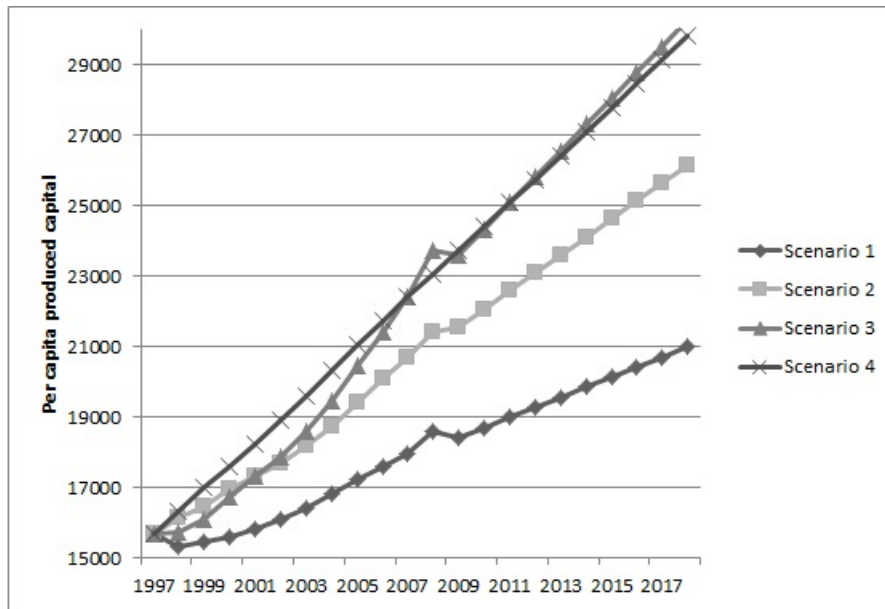
III.2.3 Robustness and final remarks

Considering the numerous assumptions and the relatively simple theoretical framework on which it is based, this counterfactual exercise it to be considered as an exercise in magnitude more than an accurate depiction of sustainability in Russia. A first obvious improvement is to account for human capital, and probably social, institutional and health capital as well to get

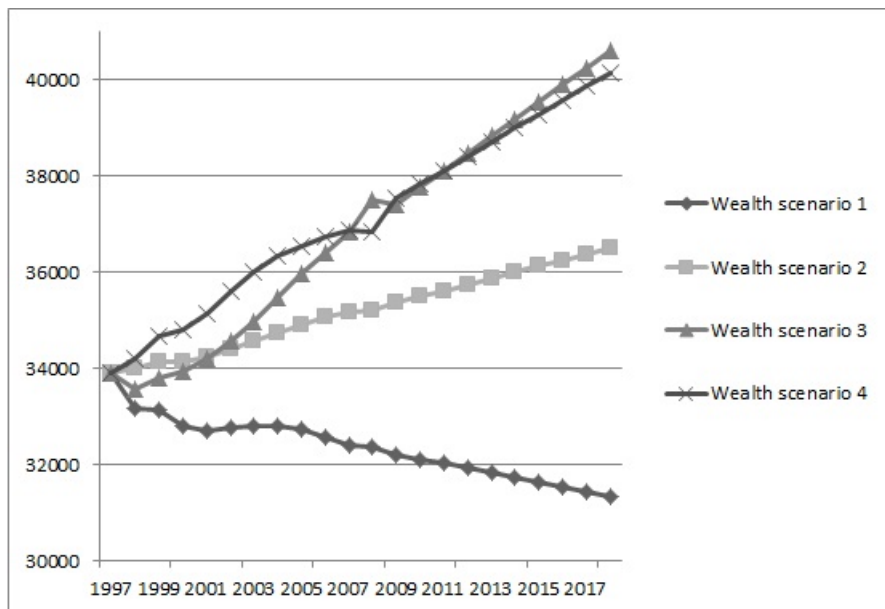
37. We do not adjust here for the fall of the Russian population as we obtain the per capita value using the 2008 population.

Figure 4.18: Forecasts on capital accumulation

(a) 2018 projections for produced capital



(b) 2018 projections for comprehensive wealth



Source: Author's calculations from the World Development Indicators(WDI), the World Bank

the bigger picture. This is unfortunately not possible under the theoretical model in [Hamilton et al. \(2006\)](#). The contribution by [Arrow et al. \(2010\)](#) used the bottom-up method to reach comprehensive wealth. Based on this method it should be possible to design more accurate counterfactuals.

As for our forecasting exercise, we base it on the assumption of a simple linear trend per series of produced capital and comprehensive wealth. We believe this model is the best fit as it yields a fairly high predictive power between 1998 and 2008. Produced capital depreciation series (see below) usually exhibit low volatility along a linear trend. Over a 10 years horizon these series have the most important impact on the trend, we therefore rely on them to guide our exercise.

The major hurdle comes from the data itself. Russian statistics are not necessarily available or reliable, especially at the beginning of the period. We could add to natural capital depreciation the impact of forestry management because of missing data. Data on the fixed consumption of fixed capital can vary extensively, without any apparent rationale. Russia witnessed an important increase in the consumption of fixed capital in 2006, which automatically leads to lower ANS. The value is also high for 2007 before dropping sharply in 2008. This may come from the end of the higher depreciation of soviet infrastructure, 20 years after the first statistics.

This may also come from new methods of fixed capital consumption computation. We contacted the World Bank about this point, we did not get an answer³⁸. The question of the depreciation of fixed capital is related to the problem of the discount rate used to compare flows over different periods of time. Changing the rate of depreciation is equivalent to changing the weight on future flows, which will end up weighting heavily on estimates of comprehensive wealth, and on the arbitrage between present and future consumption.

We present in this final section an application of sustainability concepts in the case of Russia during the second transition. We show how, from the nature of the institutions to the evolution of the role of different instruments of wealth, there is a difference between the first transition, mostly about usual development issues, and the second one where natural management and extractive institutions become the main issues. This is not to say that poverty, over mortality, employment or post communist structural change were all settled issues by 1998. We merely stress that the focus in terms of sustainability shifted from those issues to the management of natural capital.

We present the values for ANS in Russia during the second transition before comparing

38. The issue is significant as ANS and consumption of fixed capital are strongly correlated in Russia (-0.83).

it using a composite index. We discuss how ANS perform relatively well as a predictor for development paths in a comparative study. We then use a counterfactual analysis to show the consequences of the violation of the Hartwick rule in the Russian case during the period of study. Had Russia abided by the rule, produced capital per capita would be 27,6% higher in 2008 against the baseline. We also explore the long run consequences of this lack of reinvestment via a small prospective exercise up to 2018.

Our results confirm the pessimism surrounding Vladimir Putin's come back at the Kremlin in 2012. Russia did not implement any sustainable development policy during his first two mandates, it seems therefore unlikely that the course during the third will be significantly altered. A policy that does not take natural resources into account explicitly considers the rent as a free lunch. We stressed that the key to this are the institutional arrangements regulating property and management in the energy sector and here again, lack of political change at the top can only foster pessimism. The scenario for change may be triggered by the continuation of the demographic crisis. As Russia keeps losing population it may not want to squander its other assets. Still, this is unlikely as natural resources are also the favoured leverage for regional influence, as the geopolitical crisis in Belarus and Ukraine showed.

Within the limits of the exercise, more accurate data on the different instruments of wealth are critical. The important work of the World Bank can only be commended, but the international institution rests on the efforts of individual countries. Data are missing where most needed, as countries like Russia or Nigeria are first in line from a broader ecological perspective. The counterfactual exercise should be subject to more extensive robustness tests and a longer time span. In the Russian case, 10 years already produce worrying results. Monitoring potential drifts every 5 years seems in this respect the bare minimum.

Our results also suggest that institutions display more inertia than economic indicators. It is therefore hard to associate a given institutional arrangement, either extractive or inclusive with a given distribution of wealth or factor allocation. Still, the influence of institutions on the dynamic, the rate and direction of change should be accounted for. Finally, the international dimension should be completed following the principles presented in chapter 3. We cannot stress enough that wealth invested abroad is necessarily missing at home, especially if those foreign investments are controlled by an elite and returns not reinvested at home. The final recovery of the Russian federation goes through a fair extraction and allocation of the rent. This major challenge needs political, institutional and economic change to be implemented.

A final mention regarding ANS is in order. We applied the theoretical contribution in [Hamilton and Hartwick \(2005\)](#) and showed how Russian ANS although positive were too low compared to the growth rate of GDP. Increasing ANS so as to keep pace with the increase in

output is a first logical step. The consequences of going beyond are still somewhat uncharted territory. This is a problem when trying to use ANS to assess the potential disequilibria in fast growing emerging economies. This is where the role of counter-factual studies is critical.

The lower bound of sustainable development is given by the Hartwick rule, but scenarios are necessary to position the observed development path in the galaxy of potential paths. Counter-factual studies appear in that respect not only operational, but also intellectually appealing in situations where multiple equilibria and uncertainty rule. In terms of policy, it seems to us it is better to be approximatively right than precisely wrong. The natural experiment of the former Soviet Union gives us some insight on where to search for a reduction of this uncertainty: a minimal characterisation of inclusiveness and extractiveness in institutions associated with basic factor allocation rule, monitored by current values indicators.

Conclusion

In this final chapter, we explore the consequences of the findings from chapter 3. We first investigated the impact of increasing returns to scale (IRS) on the definition of the “counterfactual gains from trade” from chapter 3. We show how, although IRS do not impact factor allocation in time t , the system of relative prices in the economy is affected. In a dynamic perspective, the definition of the counterfactual gains from trade needs to be amended as those prices are going to be used to take investment decisions. IRS creates a drift in capital accumulation compared to the constant returns to scale case, another way to say that market prices do not match constant returns to scale shadow prices under IRS. We conclude logically that the gains from IRS in international trade should also be added to savings as those gains come from a reallocation of factors between sectors.

We then go on to investigate the interplaying role of trade and institutions in shaping the specialisation and resource allocation in a given country. We focus on natural resources intensive countries as they are at the forefront of sustainability issues. We investigate whether these countries develop a peculiar form of economic organisation, as defined in the literature on the resource curse. We conclude that although the majority of the literature focus on the distortions created by institutional deficiencies (mostly the extractive character of institutions) as an explanation for the resource curse, the negative feedback of trade incentives should not be neglected.

Insertion in global trade networks sends incentives that are aligned with the interests of the elite controlling extractive institutions, as trade commands specialisation in natural resources intensive goods. The relationship between trade incentives and institutions is then better seen as a vicious circle than a neutral allocation mechanism and a setting needing fixing. We illustrate this point by showing how natural resources abundant countries trade their comparative advantage goods on an inter-industrial (one way) basis, when reduction in asymmetry and sustainable development would require an intra-industrial (two ways) trade pattern. Our econometric results highlight the negative impact of resource abundance on two way trade in natural resources even as the negative impact on manufacturing production is controlled for.

Interestingly, we concur with the literature regarding the actual impact of resource abundance on growth. Once the negative impact of resource abundance on manufacturing is controlled for, we find resource abundance to have a positive impact on GDP growth. This result is consistent with the ability of extractive institutions to promote growth using the efficiency of centralisation as in ?.

We then turn in the last section to the possibilities to test for the respective impact of trade and institutional factors in undermining sustainability in resource rich countries. Although both factors are at play simultaneously in putting countries on a potentially unsustainable path, being able to estimate the respective magnitude of both effects would be precious. We can only agree with [Arrow et al. \(2010\)](#) that a theoretically rigorous answer to this question requires a theory for the “co-evolution of institutions and economic conditions” which still evades us and is well beyond the reach of our work.

We suggest a natural experiment to at least test whether resources rich countries behave (in terms of natural resources management) as a group apart, or more like culturally and institutionally close countries. Our results (to be considered with care at this stage) show that in the natural experiment of the former Soviet Union, the dynamics of ANS in the Russian Federation have more to do with some resources poor but institutionally close countries than with resources abundant countries. We consider this as further evidence that the resource curse is not only a consequence of institutional issues generated by resources abundance. It is much more a consequence of the failure to design proper structural change, which may not be harder to conduct with a comparative advantage in natural capital. The early conclusions from this natural experiment would clearly support regional policies playing on institutional and trade ties, more than targeted institutional or structural reforms country by country.

These early findings clearly call for more investigation. We identified the potential role for IRS in a sustainability context, but the impact on the links between sustainability and interdependence between trading partners is not clear. An international division of the productive processes clearly increases further interdependence, which we considered in chapter 3 not to be in the best interest of sustainability as it may prevent structural change. On the other hand IRS magnify the gains from trade and put resources to better use. We have here an emerging trade-off between efficiency by insertion in the global supply chain and control, management of the domestic development process. This trade-off is not new, but clearly takes a new dimension in the sustainability context. If one considers the critical role of uncertainty, the balance between gains from trade and sustainability by complete control over the domestic development path may be upset in favour of the later. Therefore, as stressed by [Ethier \(1979a\)](#), IRS call for some rethinking on national economic policy.

Our findings also suggest that interdependence in the development path might be more relevantly studied at the regional level. Should this result find more robust confirmation, it would clearly make the case for regional economic and political integration on the ground that there is already a strong institutional co-evolution fostered by cultural, economic and political ties. The best way to deal with the resource curse is probably not to take countries one by

one but to “nest” resource abundant countries in the relevant web of regional interdependence. This casts an interesting light on the debate in the trade literature between regionalism and multilateralism. IRS call and regional institutional and economic co-evolution clearly makes a strong case for a form of regional co-management of resources on sustainability grounds. Note this is consistent with our early observations on the key role of subsidiarity for efficient development paths in chapters 1 and 2. Based on these conclusions we can therefore predict a bright future to regional blocks. Ironically, considering the current issues in the eurozone, their future might be brighter the more institutionally homogeneous and economically heterogeneous they are.

General Conclusion

IN this thesis, we first proposed a definition of sustainability. We define sustainability as the suitable management of the *means* for a sustainable development. Sustainability can be characterised as the combination of a theory for the instruments, objects (the means themselves) and a theory to assign value to those instruments. The means (the instruments) are defined under capital theory. We traced back the origin of capital theory to the early work of Fisher (1906). Capital theory is a conceptual tool designed to describe the relationship between human-beings and their environment, material or immaterial. Capital theory gives a relative³⁹ value to instruments that can then be used to produce and to consume. As a consequence, capital theory is the first building block of sustainability.

The second building block is the theory of value. The notion of value is evidently polysemic but one of the *raison d'être* of economics is to set a value on objects and concepts. What matters is that any conception of value is rooted in a philosophical theory of social priorities and individual preferences. The most commonly used theory of that kind in economics is utilitarianism. We present utilitarianism briefly in the general introduction. We then use it in chapter 1 to introduce the neoclassical model, which is the basis for the weak sustainability paradigm.

Different academic traditions have different perspectives on sustainability. The main bone of contention is usually the degree of substitutability between different instruments of wealth. The question of substitutability is nonetheless related to other dimensions of sustainability. Using as a foundation the relation between human beings and their environment, we present a conceptual framework for sustainability. This framework is based on a simple intuition: a minimum set of rules should be respected just to maintain the possibility for present and future generations to exert their right to free will. As a consequence, a minimal set of non contradictory principles should be applied in any society, a “common ground” without which no sustainable social organisation can thrive.

We summarise those principles in five points. Sustainability consists in maintaining comprehensive wealth over time, maintaining constant consumption over time, controlling for money-value substitutability to be consistent with physical substitutability, guaranteeing intergenerational equity and fostering intragenerational equity. On this basis, sustainability should be implemented following the subsidiarity principle. To keep decision making the closest possible to the relevant scale would guarantee voice and institutional inclusiveness for all the agents. The

39. Relative to the human-beings using the instruments of wealth.

subsidiarity principle creates consistency between the object (sustainability) and the structure (inclusive institutions).

The implementation of sustainability naturally needs to be monitored and assessed. Several indicators exist to this end. The most firmly established and theoretically consistent is Adjusted Net Savings (ANS) proposed by Pearce and Atkinson (1993) and now computed by the World Bank (2011). ANS are a current value indicator, so that it encompasses the forward looking dimension of sustainability. ANS are therefore best suited to assess the sustainability of the development path on which a social group is embarked. Monitoring sustainability requires current value indicators to assess the general consistency of the path. But uncertainty makes short run adjustments of the path necessary, especially in the face of potential “critical junctures” or path dependence. Current value indicators should be supplemented by present value indicators and counterfactual scenarios to offer the most comprehensive possible assessments of sustainability.

International trade is a complicated object in this perspective. International trade emerges in a “grey area” for sustainability, as it prospers in a partial institutional vacuum between state level institutions and a handful of international organisations. International trade is a challenge for the subsidiarity principle as it creates a mismatch between the relevant level where some issues should be tackled and the level where it is institutional possible to tackle them. Biodiversity protection in critical ecosystems comes to mind. This problem should ideally be solved by scaling-up the adequate decision making process. In practice, such a move would involve a transfer of power that is unlikely to happen.

If rising to the challenge is impossible, then sustainability issues should be scaled-down to be manageable under the current institutional setting whenever it is possible. Even this *a priori* simple solution could be very hard to implement. The world today is more and more economically integrated as we go through the second globalisation. Globalisation differs in essence from simple trade expansion. When trade expansion is a plain increase in the volume of goods and services exchanged *ceteris paribus*, globalisation describes increased interdependence. In phases of globalisation, supply chains are scattered in different countries, instruments of wealth are invested across borders, consumers gain access to both foreign goods and foreign practices and habits.

An already important literature on trade and the environment explores the consequences of trade-induced factor reallocation on pollution. Authors in this field implicitly assume that world is converging towards an integrated equilibrium. The other extreme, in the literature on open economy exhaustible resources management, investigates the impact of the exogenous, world price system on domestic instruments of wealth. A final trend in the literature is to quantify the

exhaustible resources embodied in trade flows to determine who the final consumer is and the true responsibility for depletion. Responsibility for depletion highlights the difference between domestic sustainability and “virtual sustainability” where the importance of interdependence is taken into account.

Globalisation generates increased interdependence. As a consequence, sustainability issues tend to endogenously increase in scale in a globalised world as the number and the geographical dispersion of agents involved in a given situation also increase. In this context, scaling-down (which would be a second best) requires a characterisation of interdependence to discriminate between forms of interdependence that are compatible with sustainability and those which are not. On this basis, the decision to liberalise trade flows should be taken after a careful review of the position of the domestic instruments of wealth relative to the rest of the world. Conversely, if liberalised trade is proven to hinder sustainability some safeguard measures using trade management instruments should be implemented. Those measures would allow to control for “fungibility”, the substitution of a given instrument of wealth amongst different geographical scales.

The notion of comparative advantage, central to international trade theory, bears affinity with sustainability theory. A natural affiliation can be made between the notion of comparative advantage based on factor endowments and the distribution of instruments of wealth in a given country. Trade theory encourages specialisation alongside the comparative advantage when sustainability monitors investment/depletion behaviours of instruments of wealth. Assessing the impact of interdependence on sustainability requires a framework to understand how trade incentives to specialise impact the sound management of instruments of wealth on a development path. When this management implies to substitute a man made instrument for an exhaustible one, it is termed structural change.

To complete this framework for open economy sustainability we use a dynamic Heckscher-Ohlin model to test interdependence and asymmetry in endowments. Our model is based on four different instruments of wealth to study substitutability. We also propose several scenarios to study cases of structural change and pursued comparative advantage. We discuss the likelihood of steady-state convergence by calculating a path of constrained steady-states. International trade leads to polarisation in the trading partners. As the two countries engage in international trade they are impacted by (positive or negative) idiosyncratic shocks in their partner. Using trade management instruments could then be especially useful to protect instruments of wealth that form the basis for reduced asymmetry and diversification of the domestic production.

This model is based on constant returns to scale, so that we observe lost productivity between autarky and free trade as the global supply chain grows more complex. In the final

chapter, we explore the potential impact of increasing returns to scale (IRS) on sustainable paths. The trend of increased interdependence via the segmentation of the production process between countries has a dynamic impact on the decisions regarding wealth instruments allocation. A specific case has been extensively studied in the literature, the “resource curse” scenario. The resource curse is the tendency for resources rich countries to have lower GDP growth than resources poor ones. This result is related to the “Dutch disease”, where trade induced reallocation across sectors leads to the shrinkage of manufacturing in resources rich economy. We show how an inter-industry pattern of trade in resources rich countries is a sign for a lack of structural change. The resource curse is therefore another failure to set the considered country on a sustainable open economy path.

We discuss the importance of institutions to guarantee sustainability. Still, we consider those institutions to be determined outside of our framework. We mention only the instrumental value of those institutions for sustainability. We finish our study of sustainability and international trade with an application of ANS to the case of Russia. The Russian Federation and the former Soviet Union constitute a natural experiment for the relative importance of interdependence and institutional co-evolution against objective factors (such as resource abundance, climate) in setting sustainability paths. We conclude that Russia is on an unsustainable path and that this performance is most closely associated with countries that are institutionally and geographically close. This preliminary finding stress how interdependence, lacking effective global regulation, gives a rationale for regional integration between countries that are institutionally similar but asymmetrically endowed in instruments of wealth.

In the course of this work, we covered a lot of material, trying to offer a unified perspective on sustainability. As this thesis draws to a close it seems useful to offer a synthesis of our contributions.

We started with two contributions, methodological and conceptual in nature. We proposed in chapter 2 a survey of the articles related to sustainability and international trade. Considering the diversity of the efforts and the numerous modelling strategies used to address this question, this survey is filling a gap in the literature. This work allowed us to point at the most important gap in the literature to assess trade and sustainability: the need for a dynamic model of trade. The most comprehensive model is the [Copeland and Taylor \(1994\)](#) model but it is essentially static. What is needed is a model for the interactions between dynamics of accumulation and trade incentives.

Our second preliminary contribution lies with the integrated framework for sustainability assessment. We believe the separation between capital theory and the theory of value to be fruitful. This separation stresses the necessity of a philosophical background for the theory

of value. Capital theory only requires the recognition that human-beings consume and use instruments of wealth. In our framework we put the weak versus strong sustainability debate in a broader perspective. We insist that money-value substitutability is the real challenge, not physical substitutability. In this “social” perspective, substitutability is as much a spatial as a time problem. We propose to limit the use of substitutability to the time problem and use the term “fungibility” to discuss substitution across spaces.

Discussing those issues lead us to an understanding of international trade as a blind spot in sustainability. International trade brings interdependence and uncertainty. This translates into the possibility of multiple equilibria, within and between free trade and autarky. Our first key contribution is borne out of the analysis of international trade in chapter 3. We show how coordination costs in international trade can affect the sustainable paths for structural change. We show how looking for comparative advantages may reduce overall efficiency. As a consequence, countries should consider asymmetry in the distribution of their instruments of wealth when discussing free trade. Free trade is more interesting when both countries are characterised by high asymmetry in the distribution of endowments. Low asymmetry renders trade liberalisation quite unappealing.

We then show in a second key contribution (in the same chapter 3) how interdependence implies a shared responsibility for the investment/depletion behaviour of both countries. International trade alters optimal paths, creating at the same time multiple constrained steady-states. Those are constrained steady states as they depend on the evolution of variables and parameters that are not determined by international trade. Interdependence is created under the complete specialisation case where both countries have different factor prices and keep some pricing autonomy. Interdependence is maximised in the integrated equilibrium where factor prices are equalised.

Those two different trade settings show how international trade creates alignment (or symmetry) in investment/depletion policies in the two countries. This has an impact on how they move together from high to low asymmetry. But it also has an impact on how countries react to asymmetric shocks. If an idiosyncratic shock takes place in country 1, it is the most affected in complete specialisation. In the integrated equilibrium the most affected is country 2. Shocks are transmitted through traded goods and factor prices when they are equalised. This is what we call the “burden sharing” property of international trade.

In the context of sustainability this interdependence is critical. First, because in terms of precaution and uncertainty it creates the need for the co-management of the *de facto* shared resources. Second, because domestic sustainability indicators must take those dynamics into account if they want to stand a chance to a) reflect true sustainability and b) keep some

amount of predictive power. Open economy sustainability assessments depend on the joint use of current and present value indicators with counterfactual scenarios for free trade, imperfect trade and autarky comparisons.

The next key contribution is a proposal to amend Adjusted Net Savings in line with our findings. We presented, analysed and used ANS in the four chapters. We did so as ANS are grounded in theory and perform decently as a predictor of future sustainability. Our analysis stressed the importance of monitoring the overall savings rate but also to monitor each instrument of wealth and its contribution to the overall rate (following the precautionary principle). Based on our results in chapter 3 we propose to amend ANS for international trade. We show how countries in autarky face higher costs on the transition path compared to free trade. This “cost saving” property of international trade results in an evolution of domestic specialisation and alters the investment/depletion path.

We recommend that the amount saved by undertaking structural change in free trade against autarky should be saved and added to ANS. This amount should then be reinvested to undertake structural change. Exhaustible resources in particular witness a slower price increase under free trade than in autarky when those resources constitute the comparative advantage. As a consequence, free trade does increase the pressure for resource depletion and proper reinvestment must be conducted. If the domestic economy fails to do so, then the trade partner could face a shortfall in the supply of resources, putting sustainability in both countries in jeopardy. Still, cooperation under free trade is a second best compared to the balanced factor use in autarky.

Our next key contribution is presented in chapter 4. We investigate the impact of increasing returns to scale on accumulation patterns. As we demonstrated that international trade causes higher coordination costs from the industrial restructuring, the observed gains from trade must come from another source. The international division of the production process (IDPP) is based on international economies of scale. Countries have an incentive to split the production process to develop economies of scale by increasing international specialisation. We use the [Ethier \(1982\)](#) model to show how increasing returns to scale do not affect factor allocation in a static setting. Economies of scale emerge from the reorganisation of tasks between countries, but factor allocation is unchanged compared to the constant returns to scale case.

There is however a catch. Although the technical equilibrium is unchanged, international returns to scale change factor prices. As a consequence, incentives to invest in the next period are altered. Increasing returns to scale will therefore change the distribution of instruments of wealth in both countries, towards greater interdependence again. Gains from trade emerging in this process should be added to ANS and reinvested to preserve a minimal level of diversification

in endowments. This finding is also first evidence that the rationale for the establishment of the global supply chain does not matter for sustainability. What matters are the consequences on sustainability paths.

This observation leads us to question the impact of the nature of trade on sustainability paths. We focus on the resource curse as a prime example of the distortion set by asymmetry in the distribution of endowments on a development path. We first review the literature and show how institutional and trade motives interplay in the resource curse. International trade encourages specialisation which reinforces economic extractiveness, which in turn reinforces specialisation and so on. We then show how resource abundance negatively affects intra-industry trade in primary goods. Resources rich countries trade more than the average resources intensive goods against other goods. As a consequence, they can use the factor content of trade as a substitute for domestic structural change.

Inter-industry trade in natural resources abundant goods is therefore an indicator of delayed structural change. We suggest it is the sign that resources rich economies tend to deplete exhaustible resources before considering structural change when an alternative engine for growth is needed. The consequences for the analysis of the resource curse are clear. We confirm that resources abundance is not so much correlated with lower growth but with a shrinking manufacturing sector. The resource curse is in essence a problem of excessive specialisation (and therefore sustainability) rather than a problem of aggregate growth.

Our final contribution is an empirical assessment of modern Russia using ANS. We show how Russia and the former Soviet Union are an interesting natural experiment to test the importance of institutional factors in shaping the development path. We show that the evolution of ANS for Russia is a better match to countries that are institutionally similar, compared to countries that have a similar distribution of endowments. Hence, the distribution of endowments is correlated with the levels of ANS while ANS variations are correlated with institutional similarities. This finding gives credit to the idea that integration could be conducted between countries that are institutionally similar even if their distribution of instruments of wealth is different.

It also suggests that countries that have no desire to generate mutual dependence with other countries should probably monitor the nature of their trade flows much more closely. It is one thing to be exposed to the adverse consequences of an overall fall in the volume of trade. It is quite different to suddenly lose a partner with a relative advantage in a instrument of wealth that is scarce in the domestic market. In that situation, our scenarios in chapter 3 show that the consequences are the most severe.

Based on those contributions, we discussed on several occasion the opportunity (notably for

resources rich countries) to liberalise trade. We approached the problem using several angles. We questioned the timing of trade liberalisation, its impact on domestic specialisation, the potential relocation of parts of the production process abroad and the importance of interdependence. The case for trade liberalisation is, to say the least, embattled in a sustainability context. We should probably stress one last time that it is our *normative* approach that leads to question the rationale for trade. From a more conventional perspective, as gains from trade can be expected (and critically, productivity improvements) the literature generally sees trade in a favourable light. We departed from that perspective to give a more nuanced picture of trade liberalisation on sustainability grounds.

The starting point is our understanding of wealth and the composition of wealth as central tenet of sustainability. As a consequence, sustainability demands diversification in the instruments of wealth in the domestic economy. This is for protection against uncertainty and to give the agents more flexibility over the evolution of the economy, which usually takes the form of structural change (the substitution of some widely used instruments of wealth with new, more productive ones). The logic of international trade is instead to increase the specialisation of the economy to generate gains from an increased international division of labour (under constant or increasing returns to scale). The decision to liberalise trade should therefore be taken by considering the potential benefits of increased specialisation against the sustainability imperative of diversification.

Trade liberalisation should always be undertaken with a clear purpose. In chapter 3 we present a simple rationale: cost saving in the wake of structural change. A corner case of this rationale is reached when some instruments of wealth enter as complements in the production process. In that scenario, the domestic demand elasticity for those instruments is null, so that trade liberalisation is not only desirable (to alleviate costs) but unavoidable (simply to keep the domestic economy running). The two rationale left for trade liberalisation are the possibility to access new goods (i.e. new technologies and *savoir faire*) or to access foreign varieties of the domestic goods and to improve domestic total factor productivity via foreign technology transfers.

In any case, the distinctive mark of trade liberalisation is increased interdependence, the consequences of which should be considered carefully. The first consequence of increased interdependence is increased specialisation. Specialisation can either take the form of a reduction in the number of sectors covered by domestic production, or a change in the composition of the parts of the global production processes that are produced domestically. We stressed in the context of the resource curse the dangers associated with a concentration of the production in a reduced number of sectors (in terms of political and economic inclusiveness). But there are

also dangers in entering the global supply as a producer of a similar component in different sectoral production processes. This form of interdependence is potentially more balanced (every country needs all the other countries) but increases specialisation much more markedly. The responsibility for production falls on a much more limited number of instruments of wealth.

As a consequence, each and every country may desire structural change, but the global trading system may not necessarily send any incentives to go in this direction. Countries have to undertake structural change against the organisation of the international system of interdependence. Reduction in interdependence is potentially destabilising, if one country reduces its dependence on the others while the others fail to reciprocate. The distribution of global comparative advantages is therefore subject to asymmetric shocks. Those shock may destabilise the trading system as the adjustment to those shocks is unevenly shared across the system. It is nonetheless impossible to forbid countries to depart from their comparative advantage as departure is in the interest of sustainability. The only viable option is to create a global management of sustainability paths in countries that are already interdependent.

This is the final lesson of our work. It is certainly not new, but deserves repetition as the lessons of the past seems to be forgotten in Europe and elsewhere. Sustained trade flows between countries are necessarily the first steps towards a form of economic integration. Trade is too much of a disruptive force for all countries to allow it to shape development paths uncontrolled or unchecked. Sooner or later, either the volume or the structural impact of trade⁴⁰ will recede under domestic pressure. And once a form of economic integration is reached, some steps for political cooperation and integration will be undertaken as it will then be in the interest of the stakeholders. It is impossible to maintain uncompromising free trade and sustainability without political and economic integration. The necessary outcome of extended free trade without political and economic integration is a state of subjection to the rule of specialisation. Sustainability is then hindered, if not prevented.

International trade should never prevent diversification in either the domestic economy or the trading partners. Asymmetric shocks from unilateral diversification should be managed, so that the burden of adjustment is fairly shared between trading countries. In this perspective, trade management instruments could legitimately be used to limit fungibility and money-value substitutability. The alternative to autarky is not necessarily free trade. Managed trade could make for the cohabitation of efficiency gains from trade with the necessary diversification, especially at the regional level. Tariff revenues could be allocated to the funding of structural

40. Reduction in the volume of trade would be a plain reduction of the intensive margin of trade. The structural impact of trade is the ability to shape specialisation because of world prices. The structural impact of trade can be lowered using protectionist measures, productivity improvements or product differentiation strategies.

change.

Trade management instruments are second best instruments. A final note may make them worth considering in any case. In the course of this thesis, we represented firms as passive maximising agents, within countries boundaries. It is obviously a simplifying assumption as we focused on instruments of wealth. In a phase of globalisation, international firms operate the global supply chain and have interests that do not necessarily coincide with the geography of the polities. In this context, tariffs are as legitimate as any tax to channel income from one category of agents to another. Those tariffs would in an ideal world be levied by an international structural fund, in charge of managing global issues and alleviate the constraint on structural change at the country level. Lacking this first best, the case can be made for countries or regional blocks to do so. This is one way to partially reduce the “grey area” in which international trade currently evolves.

We will now end this presentation with a brief discussion on potential leads for future research. We present these chronologically, arguably the best mode for an agenda. For ease of reading, we present those leads from the most immediate research avenues to a more ambitious long run agenda.

To follow through with the model in chapter 3, the dynamic model should be amended. The current setting, where three factor are exogenous, is useful to test scenarios of structural change. It would also be interesting to give the representative agent more latitude to allocate resources. Of prime interest is the question of the spontaneous emergence of structural change. The representative agent should balance the extra income from immediate gains from trade with the opportunity to have a more diverse productive base in the future. A second natural step is to bring our results on increasing returns to scale in chapter 4 to the production structure of the model. Increasing returns to scale can certainly tilt the balance in favour of international trade. It would also be interesting to explore the consequence of increasing returns to scale in intermediate goods compared to consumption goods.

We presented the impact of trade on sustainability using an Heckscher-Ohlin model, to be able to model factors explicitly. Doing so, we focused on the impact of trade on the domestic economy, more than we explored whether observed trade flows were or not compatible with sustainability. Doing so would require to explore the impact of the taste for variety, or productivity differences on the distribution of factors. We should therefore build a joint model for productivity and factor endowments motives for trade and see how productivity differences may change our results. Taste for variety is a different challenge. Following the current debate on sustainable consumption, there is clearly an arbitrage to investigate between more varieties from trade and sustainability. A balance between transaction costs, preferences and measures

of entropy needs to be found for a “sustainable degree of variety” in consumption. Such a balance can not exist independently of an ethical position on consumption.

Further down the road, two larger research avenues need to be explored. The concept of “fungibility” should lead to a rethink of the allocation of resources between the regional and country level. What is at stake here is a definition of a responsibility to promote optimal regional diversification while benefiting from international specialisation. This is not an easy task, so that careful regional economic and political planning should be organised. From a theoretical perspective, the challenge is to propose criteria for new basic units in economic analysis. Countries have always been the default geographical unit, the way the representative firm and the representative agent are the basic blocks in microeconomics.

Our aim exploring fungibility will be to establish criteria (and indicators) to define regional units that would be consistent with sustainability. Those units may be subdivisions in countries, gathering of countries, or more problematically a gathering of administrative regions from several countries. Based on those units, interregional trade flows could be designed in line with sustainability requirements, to propose a counterfactual trade system. Deviation from this trade system could then be used as a basis for the use of trade management instruments to levy and reinvest gains from trade or correct trade flows for sustainability.

The second important avenue has to do with finance. Under our current economic organisation, financial flows are the counterpart of instruments of wealth. Fisher-type perfect substitutability in instruments of wealth makes it possible to move in money-value form those instruments all over the planet. We presented in chapters 3 and 4 the many contributions studying the consequences of this possibility. We also stressed that in theory, the Fisher capital theory can accommodate imperfect substitution between instruments of wealth. There are therefore many efforts to devote to the analysis of imposed limited money-value substitutability. On a related topic, the expansion of wealth accounting and natural capital is going to “create” many new assets in the current financial system. The impact of those assets on the financial system (and vice versa) should also be investigated closely. There is *a priori* no reason for those assets to be immune to the documented flaws of financial markets. Those assets have the potential to increase financial instability.

All those potential research topics fit in a global effort to understand better the normative and objective rules presiding over the allocation of the limited resources at our disposal. In this perspective we strongly believe that sustainability is nothing less than the *raison d'être* of economics as a discipline in the XXIst century. When pioneers such as Nicholas Georgescu-Roegen, Allen Kneese or David Pearce extended our knowledge of sustainability, they saw this as the natural continuation of the works of François Quesnay, Richard Cantillon, Adam

Smith or Alfred Marshall. The current efforts of Kenneth Arrow, Partha Dasgupta or Kirk Hamilton clearly point in this direction. When considering the future of sustainability study it seems therefore safe to assume that mainstream economics will gradually take more and more of sustainability in the central corpus (at the very least on the macro side of the discipline). The questions that we hope to tackle to complete the theory of sustainability have therefore as much to do with sustainability than more mainstream economics.

The first missing link in that grand theory is an operational understanding of the famous “co-evolution” of institutions and sustainability from [Arrow et al. \(2010\)](#). Beyond the general principles of inclusiveness and exclusiveness, we still do not know much about the relationship between institutions (the superstructure) and sustainability (the objects). Building such a theory demands as a prerequisite an understanding of the impact of inequalities (intragenerational equity) on wealth accumulation. Recent contributions seem to have made breakthroughs in this direction. Should we be able to associate a distribution of wealth with an institutional evolution, we would certainly be able to discriminate between institutions that effectively foster sustainability and those hindering it.

The second missing link is closer to our topic. We stressed early in this work the difference between means and ends of development. A sustainable development should be consistent, in the sense that a sustainable development must take place within the means available. Once this condition is realised, social groups should be free to choose the possible ends of development as they fit. Those ends certainly include the choice of the perimeter of the social groups, a say in the limits of the *polis*. There is, as often when exploring sustainability, both an intrinsic and an instrumental value to economic and political integration. This is what makes (and will keep making in the future) the definition of criteria for economic integration so complicated.

Nonetheless, we will have to revisit the usual convergence criteria of the [Balassa \(1961\)](#) scale to propose a rationale for sustainable economic integration. The role of factor movements should be considered, in the regional perspective we presented above. Convergence criteria based on sustainability principles should also be designed, with an agenda for wealth management beyond market mechanisms.

This is a very ambitious scientific objective. It is also a necessity for the consistency of a theory of open economy sustainability. It is, in the end, a discussion on the possibility for complex social groups to pool resources for a common future. In that sense, it is also the original pledge of the Brundtland report. As a result, this could prove to be the ultimate test for sustainability. Sustainability challenges are enormous and the latest news on climate, biodiversity and ecosystem services are not bright.

Solutions will not come from individual initiatives and stochastic technical progress. As Jacques Ellul already knew, solutions will come from our ability to coordinate our efforts under common ends and values. We hope that this thesis will prove to be a first small step in this direction.

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APPENDIX A

**Resources allocation in the static
model**

In chapter 3 section II.1, the allocation of instruments of wealth between the five sectors is obtained from the aggregate production function:

$$Y = \Phi y_{1,i}^{\alpha/4} y_{2,i}^{\alpha/4} y_{3,i}^{1-\alpha} y_{4,i}^{\alpha/4} y_{5,i}^{\alpha/4}$$

And the intermediate goods functions:

$$\begin{aligned} y_{1,i} &= \lambda K_{l,i} \\ y_{2,i} &= \gamma K_{p,i} \\ y_{3,i} &= (K_{l,i} K_{p,i} K_{e,i} K_{r,i})^{\frac{1}{4}} \\ y_{4,i} &= \omega K_{e,i} \\ y_{5,i} &= \iota K_{r,i} \end{aligned}$$

Substituting those intermediate goods production functions into the aggregate production function yields:

$$Y = \Phi \lambda K_{l,i}^{\alpha/4} \gamma K_{p,i}^{\alpha/4} (K_{l,i} K_{p,i} K_{e,i} K_{r,i})^{\frac{1}{4} (1-\alpha)} \omega K_{e,i}^{\alpha/4} \iota K_{r,i}^{\alpha/4}$$

We derive this expression with respect to λ, γ, ω and ι . Doing so gives us:

$$\begin{aligned} \frac{\partial Y}{\partial \lambda} &= 0 \Leftrightarrow \lambda = \alpha \\ \frac{\partial Y}{\partial \gamma} &= 0 \Leftrightarrow \gamma = \alpha \\ \frac{\partial Y}{\partial \omega} &= 0 \Leftrightarrow \omega = \alpha \\ \frac{\partial Y}{\partial \iota} &= 0 \Leftrightarrow \iota = \alpha \end{aligned}$$

The α parameter is equal to the allocation parameters, so that α effectively allocates instruments of wealth across sectors.

APPENDIX B

The static equilibrium conditions

In chapter 3 section II.1, the general equilibrium depends on the technical equilibrium between the aggregate production function and the intermediate goods production function. This is true in either autarky, the integrated or the complete specialisation equilibrium. First, the unit cost of production (so that $Y = 1$ while P_y is the *numéraire*) should be minimized:

Minimize:

$$P_y = P_1x_1 + P_2x_2 + P_3x_3 + P_4x_4 + P_5x_5$$

Subject to:

$$1 = \Phi y_1^{\alpha/4} y_2^{\alpha/4} y_3^{1-\alpha} y_4^{\alpha/4} y_5^{\alpha/4}$$

The resulting Lagrangian L yields five first order conditions with respect to the goods quantities:

$$L = P_1x_1 + P_2x_2 + P_3x_3 + P_4x_4 + P_5x_5 - \zeta(\Phi y_1^{\alpha/4} y_2^{\alpha/4} y_3^{1-\alpha} y_4^{\alpha/4} y_5^{\alpha/4} - 1)$$

$$\frac{\partial L}{\partial x_1} = 0 \Leftrightarrow P_1 = \frac{\Phi \alpha \zeta x_1^{\frac{\alpha}{4}-1} x_2^{\frac{\alpha}{4}} x_3^{1-\alpha} x_4^{\frac{\alpha}{4}} x_5^{\frac{\alpha}{4}}}{4}$$

$$\frac{\partial L}{\partial x_2} = 0 \Leftrightarrow P_2 = \frac{\Phi \alpha \zeta x_1^{\frac{\alpha}{4}} x_2^{\frac{\alpha}{4}-1} x_3^{1-\alpha} x_4^{\frac{\alpha}{4}} x_5^{\frac{\alpha}{4}}}{4}$$

$$\frac{\partial L}{\partial x_3} = 0 \Leftrightarrow P_3 = -\frac{\Phi \zeta (\alpha - 1) x_1^{\frac{\alpha}{4}} x_2^{\frac{\alpha}{4}} x_4^{\frac{\alpha}{4}} x_5^{\frac{\alpha}{4}}}{x_3^\alpha}$$

$$\frac{\partial L}{\partial x_4} = 0 \Leftrightarrow P_4 = \frac{\Phi \alpha \zeta x_1^{\frac{\alpha}{4}} x_2^{\frac{\alpha}{4}} x_3^{1-\alpha} x_4^{\frac{\alpha}{4}-1} x_5^{\frac{\alpha}{4}}}{4}$$

$$\frac{\partial L}{\partial x_5} = 0 \Leftrightarrow P_5 = \frac{\Phi \alpha \zeta x_1^{\frac{\alpha}{4}} x_2^{\frac{\alpha}{4}} x_3^{1-\alpha} x_4^{\frac{\alpha}{4}} x_5^{\frac{\alpha}{4}-1}}{4}$$

Substituting those values for the prices into the objective function gives a value for the Lagrangian ζ of 1. Rearranging the first order condition using $\zeta = 1$ and the objective function gives the following equilibrium conditions:

$$\begin{aligned}x_1 &= \frac{\alpha}{4P_1} \\x_2 &= \frac{\alpha}{4P_2} \\x_3 &= \frac{1-\alpha}{P_1} \\x_4 &= \frac{\alpha}{4P_4} \\x_5 &= \frac{\alpha}{4P_5}\end{aligned}$$

Then, substituting into the unit cost production with $X = [(\Phi(\frac{\alpha}{4})^\alpha(1-\alpha)^{1-\alpha})]^{-1}$ gives:

$$1 = Xp_3^{1-\alpha}(P_1P_2P_4P_5)^{\frac{\alpha}{4}}$$

Which is our general equilibrium condition for the production of the final good. The market share conditions are derived from the rearranged first order conditions. It naturally follows from those that all the p_jx_j are equal to $\frac{\alpha}{4}$ so that $p_ix_i = p_jx_j$ for all i but $i = 3$. The market share for good 3 is obtained by taking the ratio of $p_1x_1 = \frac{\alpha}{4}$ over $p_3x_3 = (1-\alpha)$.

For the intermediate goods, the price equal marginal cost conditions are derived from the equilibrium of the firm in each sector:

$$\begin{aligned}\Pi_1 &= P_1y_1 - wK_l \\ \Pi_2 &= P_2y_2 - pK_p \\ \Pi_3 &= P_3y_3 - wK_l - pK_p - eK_e - rK_r \\ \Pi_4 &= P_4y_4 - eK_e \\ \Pi_5 &= P_5y_5 - rK_r\end{aligned}$$

With Π the profit. As inputs enter one to one in the production of intermediates, it is straightforward that equilibrium requires the price of the intermediate to be set at the price of the corresponding factor. The exception is as usual good y_3 where four factors enter production. Maximising profit for good y_3 requires to substitute for y_3 in the profit function using the production function $y_3 = K_l^{\frac{1}{4}}K_p^{\frac{1}{4}}K_e^{\frac{1}{4}}K_r^{\frac{1}{4}}$. Deriving the profit function with respect to the four

factors yields four first order conditions:

$$\begin{aligned}\frac{\partial \Pi}{\partial K_l} = 0 &\Leftrightarrow P_3 = \frac{4w}{K_l^{-\frac{3}{4}} K_p^{\frac{1}{4}} K_e^{\frac{1}{4}} K_r^{\frac{1}{4}}} \\ \frac{\partial \Pi}{\partial K_p} = 0 &\Leftrightarrow P_3 = \frac{4p}{K_l^{\frac{1}{4}} K_p^{-\frac{3}{4}} K_e^{\frac{1}{4}} K_r^{\frac{1}{4}}} \\ \frac{\partial \Pi}{\partial K_e} = 0 &\Leftrightarrow P_3 = \frac{4e}{K_l^{\frac{1}{4}} K_p^{\frac{1}{4}} K_e^{-\frac{3}{4}} K_r^{\frac{1}{4}}} \\ \frac{\partial \Pi}{\partial K_r} = 0 &\Leftrightarrow P_3 = \frac{4r}{K_l^{\frac{1}{4}} K_p^{\frac{1}{4}} K_e^{\frac{1}{4}} K_r^{-\frac{3}{4}}}\end{aligned}$$

Equalising those first order conditions using P_3 gives us two ratios $\frac{w}{p} = \frac{K_p}{K_l}$ and $\frac{e}{r} = \frac{K_r}{K_e}$. Substituting those ratios into the four first order conditions gives the same equilibrium condition:

$$P_3 = 4(eprw)^{\frac{1}{4}}$$

This demonstration holds for the autarky and the integrated equilibrium. For the complete specialisation (CS) equilibrium, differences come in the consumption shares and price equal marginal costs conditions. In CS, both countries specialise so that the entirety of goods y_1 and y_2 is produced in country 1 while the entirety of goods y_4 and y_5 is produced in country 2. As a consequence, price equal marginal cost conditions for the intermediate goods solely depend on one out of two countries endowments and factor prices for the relevant goods.

The market share condition for good y_3 is also amended as not only consumption but also production is made in both countries. The global equilibrium is left unchanged, so that the form of the equation is left unchanged. Still, production needs to be differentiated between countries 1 and 2 so that substitution in the resolution of the general equilibrium only takes place with $x_{3,1}$ and $x_{3,2}$ together.

APPENDIX C

**Recursive equilibrium for the dynamic
model**

The dynamic model in chapter 3 section II.2 is based on a representative consumer in both countries, maximising utility:

$$U_{j,t} = \sum_{s=t}^{\infty} \beta^{s-t} \ln c_{j,t}$$

Where utility in t $U_{j,t}$ is the sum of discounted consumption flows $c_{j,s}$ over an infinite number of periods, so that t goes to ∞ from the present period s . Utility is maximised subject to the budget constraint:

$$\begin{aligned} & w_{j,t}K_{l,j,t} + p_{j,t}K_{p,j,t} + e_{j,t}K_{e,j,t} + r_{j,t}K_{r,j,t} \\ & = c_{j,t} + K_{p,j,t+1} - K_{p,j,t} + \delta K_{p,j,t} + xK_{e,j,t} - \rho K_{r,j,t} \end{aligned}$$

under the structural change (SC) scenario. The constraint is the same in both countries. To solve this system we consider three endowments to be exogenous (K_l, K_e and K_r) so that our representative agents in both countries only choose a value for $c_{j,t}$ and $K_{p,j,t}$. We rearrange the budget constraint to isolate $c_{j,t}$:

$$\begin{aligned} c_{j,t} & = w_{j,t}K_{l,j,t} + p_{j,t}K_{p,j,t} + e_{j,t}K_{e,j,t} + r_{j,t}K_{r,j,t} \\ & \quad - K_{p,j,t+1} + K_{p,j,t} - \delta K_{p,j,t} - xK_{e,j,t} + \rho K_{r,j,t} \end{aligned}$$

We can then substitute the constraint into the utility function. We can then derive the utility function with respect to produced capital in $t+1$:

$$\frac{\partial U_{j,t}}{\partial K_{p,j,t+1}} = 0 \iff \frac{-1}{c_{j,t}} + \beta \frac{1}{c_{j,t+1}} (1 - \delta + p_{j,t}) = 0$$

Which gives us the first equation of motion:

$$c_{j,t+1} = \beta c_{j,t} (1 - \delta + p_{j,t})$$

This first equation of motion can then be used to obtain the steady-state value. In steady-state, consumption is constant over time, so that $c_{j,t+1} = c_{j,t}$. The first equation of motion becomes:

$$\frac{1}{\beta} = 1 + p_{j,t} - \delta$$

Under the comparative advantage (CA) scenario, the budget constraint changes for country 2 :

$$\begin{aligned} & w_{2,t}K_{l,2,t} + p_{2,t}K_{p,2,t} + e_{2,t}K_{e,2,t} + r_{2,t}K_{r,2,t} \\ & = c_{2,t} + K_{r,2,t+1} - K_{r,2,t} - \rho K_{r,2,t} + \delta K_{p,2,t} + xK_{e,2,t} \end{aligned}$$

So that the same procedure yields a slightly modified equation of motion:

$$c_{2,t+1} = \beta c_{2,t}(1 + \rho + r_{2,t})$$

APPENDIX D

The distribution of wealth in countries worldwide

The following three tables give the per capita values for labour/human capital K_l , produced capital K_p , exhaustible resources K_e and renewable exhaustible resources K_r . We get those values from the World Bank Wealth Accounting database, available here.¹ All values are in 2005 USD. We then sum the values for labour and produced capital and compute the share of those instruments of wealth in comprehensive wealth. This gives the “country 1 percentage”, the share of instruments corresponding to a country one type specialisation. We then compute the same percentage with exhaustible resources (renewable and non-renewable) to obtain the “country 2 percentage”.

We then use the factor price equalisation (FPE) condition defined in chapter 3 section II.1.3 to assess the likelihood of FPE in the considered year. We keep our benchmark value of 0.15 for α , so that FPE occurrence is to be understood as a mere indication. Even under this very crude assessment of FPE, the share of countries under FPE is decreasing over the years. In 1995, 27 countries out of 125 satisfied the FPE condition. The corresponding numbers are 31 out of 149 for 2000 and 28 out of 152 for 2005. This represents 24%, 21% and 18.4% of the sample respectively. Therefore, when all the instruments of wealth are considered, FPE is rather the exception than the norm in international trade. Under our benchmark parametrisation, FPE breaks down when a given country owns more than 59.25% of its wealth in produced capital or labour on the one hand or exhaustible resources on the other hand.

1. <http://databank.worldbank.org/data/views/variableselection/selectvariables.aspx?source=wealth-accounting>

Distribution of wealth instruments and FPE in 1995

Country	Total	Produced Capital	Human Capital	Renewable Resources	Non-Renewable Resources	Country 1 %	Country 2 %	FPE
Algeria	26298.9041	11561.6128	6452.05284	2720.68874	5564.54968	68.4958796	31.5041204	No FPE
Argentina	38046.0398	11055.7396	21141.9798	5148.99859	699.321715	84.6283073	15.3716927	No FPE
Australia	232497.04	90926.6422	112029.433	21395.8913	8145.073	87.2940471	12.7059529	No FPE
Austria	248794.864	96185.4752	141643.909	10727.5773	237.902633	95.5925618	4.40743823	No FPE
Bahrain	141815.628	52266.1259	32479.4508	1372.55969	55697.4916	59.7575725	40.2424275	No FPE
Bangladesh	3113.61337	610.138777	1419.39521	1040.76947	43.3099162	65.1825947	34.8174053	No FPE
Belgium	223913.621	84756.073	135618.774	3538.07785	0.69624273	98.4195807	1.58041931	No FPE
Belize	37684.159	7830.32594	7697.90158	22155.9314	0	41.2062467	58.7937533	FPE
Benin	6883.73177	852.90773	1187.08514	4791.30844	52.430458	29.634985	70.365015	No FPE
Bhutan	17304.393	3386.27451	-	17802.7284	33.8627133	-	103.075508	No FPE
			3918.47259			3.07550848		
Bolivia	12583.4197	1921.42008	2470.49236	7484.11233	707.394885	34.902376	65.097624	No FPE
Botswana	25581.4873	9912.92962	9106.47733	6318.17107	243.909325	74.3483234	25.6516766	No FPE
Brazil	40661.3848	11831.1262	18209.4757	9879.008	741.774858	73.8799283	26.1200717	No FPE
Brunei	197130.71	63981.8692	-	8996.925	124460.227	32.3001717	67.6998283	No FPE
Darus-salam			308.311394					
Burkina Faso	3973.582	766.839109	994.324965	2212.41793	0	44.3218254	55.6781746	FPE
Burundi	2054.36064	261.978132	301.676477	1490.06316	0.64287545	27.4369844	72.5630156	No FPE
Cameroon	10261.4935	2792.29125	2756.94118	3911.68032	800.580782	54.0782139	45.9217861	FPE
Canada	237284.661	76284.176	128505.391	27681.2656	4813.82826	86.3054385	13.6945615	No FPE
Central African Republic	7655.04702	638.216759	-	7344.19873	0.38183729	4.05570929	95.9442907	No FPE
			327.750305					
Chad	5917.25652	381.422508	834.655096	4701.17892	0	20.5513754	79.4486246	No FPE
Chile	45463.627	12227.8366	22041.4999	6187.36716	5006.92331	75.3774804	24.6225196	No FPE
China	7122.46162	2522.84664	1568.69162	2602.5184	428.404955	57.4455642	42.5544358	FPE
Colombia	27300.9706	6733.74174	12965.7479	6331.10403	1270.37687	72.1567375	27.8432625	No FPE
Comoros	7785.63329	2353.69351	3478.42448	1953.51529	0	74.9087169	25.0912831	No FPE
Congo,	2708.01281	353.739255	163.099193	2091.82211	99.3522532	19.0855245	80.9144755	No FPE
Dem. Rep. Congo,	17891.2125	5889.67277	-	6111.20646	8582.72006	17.8707059	82.1292941	No FPE
Rep.			2692.38681					
Costa Rica	36058.8743	8397.82619	16923.4803	10737.519	0.04880881	70.2221213	29.7778787	No FPE
Côte d'Ivoire	8976.72512	2048.67602	4208.31275	2680.97104	38.765315	69.7023545	30.2976455	No FPE
Cyprus	154062.804	55476.0106	87438.4217	11144.7911	3.58043765	92.7637488	7.23625122	No FPE
Denmark	311752.062	107277.532	188108.414	13425.5533	2940.56245	94.7502783	5.24972174	No FPE
Dominica	39159.8033	12106.909	14840.1209	12212.7734	0	68.8129859	31.1870141	No FPE
Dominican Republic	24545.0574	6129.33759	12828.8472	5453.7015	133.17104	77.2382991	22.7617009	No FPE
Ecuador	28041.93	6470.29289	7169.26744	10262.6389	4139.73081	48.6398773	51.3601227	FPE
Egypt,	10232.7994	2799.36003	4099.04877	2355.37598	979.014585	67.4146786	32.5853214	No FPE
Arab Rep. El Salvador	22595.8105	4787.51127	13075.9312	4732.36804	0	79.056436	20.943564	No FPE
Ethiopia	2145.54346	248.431091	241.756819	1655.09539	0.260163	22.8467947	77.1532053	No FPE
Fiji	34064.3168	7725.17509	8882.46342	17016.3755	440.302804	48.7537695	51.2462305	FPE
Finland	224488.48	90934.2767	114378.816	19121.2614	54.1252615	91.4581868	8.54181323	No FPE
France	238449.357	84223.6173	145187.714	8955.59748	82.4283816	96.2096665	3.7903335	No FPE
Gabon	64524.6664	29620.416	3484.87976	10978.9342	20440.4365	51.306419	48.693581	FPE
Gambia, The	2943.8258	714.72669	1465.2731	763.826014	0	74.0532876	25.9467124	No FPE
Germany	234126.644	90242.9479	138348.11	5324.48535	211.101501	97.6356442	2.36435578	No FPE
Ghana	4657.4909	627.608371	1602.63252	2421.4356	5.81440868	47.8850295	52.1149705	FPE
Greece	156229.304	63586.5551	82865.7254	9606.06314	170.960289	93.7418761	6.25812391	No FPE
Grenada	33311.503	14129.8677	16450.7417	2730.89367	0	91.80195	8.19805	No FPE
Guatemala	23010.9688	4441.36378	7737.28066	10742.8551	89.469232	52.9253878	47.0746122	FPE
Guinea	3725.18917	699.588548	1013.3891	1614.92831	397.283205	45.983642	54.016358	FPE
Guinea-Bissau	4863.28285	970.988143	1161.38224	2730.91246	0	43.8463164	56.1536836	FPE
Guyana	22516.5356	4082.6645	-2481.7164	19990.0736	925.513853	7.11009954	92.8899005	No FPE
Haiti	6312.27765	1494.97373	2722.97537	2094.32856	0	66.8213492	33.1786508	No FPE
Honduras	13733.4809	3295.50567	3196.41284	7217.04632	24.5160446	47.2707435	52.7292565	FPE
Country	Total	Produced Capital	Human Capital	Renewable Resources	Non-Renewable Resources	Country 1 %	Country 2 %	FPE

Distribution of wealth instruments and FPE in 1995

Country	Total	Produced Capital	Human Capital	Renewable Resources	Non-Renewable Resources	Country 1 %	Country 2 %	FPE
Hong Kong, China	139963.716	60820.7932	79138.3886	4.5339939	0	99.9967606	0.00323941	No FPE
Hungary	68420.3282	30510.1052	29514.9874	7397.49645	997.739178	87.7299103	12.2700897	No FPE
Iceland	325989.858	111596.317	196911.5	17482.041	0	94.6372439	5.36275611	No FPE
India	5630.05943	1160.93363	1056.06309	3228.43412	184.628591	39.3778564	60.6221436	No FPE
Indonesia	10367.0224	3327.86809	3635.35288	2782.02599	621.775433	67.1670294	32.8329706	No FPE
Iran, Islamic Rep.	21505.5138	7403.53508	2772.58116	3917.5157	7411.88189	47.318638	52.681362	FPE
Ireland	197648.327	60230.0708	120043.316	16667.5205	707.41939	91.2091642	8.79083583	No FPE
Israel	139806.437	42876.1655	91745.8079	5177.05387	7.40942226	96.2916848	3.70831516	No FPE
Italy	213997.782	82228.8016	123529.916	7894.68208	344.382513	96.1499299	3.85007009	No FPE
Jamaica	39339.2574	10784.6196	17737.3737	8013.65478	2803.60927	72.5026226	27.4973774	No FPE
Japan	251630.802	127581.333	120448.073	3580.60315	20.7932171	98.5687776	1.43122239	No FPE
Jordan	19711.3578	6897.08805	10028.5039	2780.40069	5.36512613	85.8672049	14.1327951	No FPE
Kenya	6910.52646	1442.84707	1405.37138	4062.27544	0.0325616	41.2156508	58.7843492	FPE
Korea, Rep.	83025.3586	37026.3123	43162.2536	2835.15555	1.63719626	96.5832213	3.41677868	No FPE
Kuwait	260049.01	66130.641	54481.6939	1351.67542	138084.999	46.3806169	53.6193831	FPE
Lesotho	9248.48472	3575.15519	4581.43531	1091.89423	0	88.1938041	11.8061959	No FPE
Luxembourg	350540.159	147654.564	191801.33	11084.2646	0	96.8379473	3.16205272	No FPE
Macao, China	88031.7597	52346.3682	35685.3914	0	0	100	0	No FPE
Madagascar	4362.3794	444.413258	681.514329	3236.42473	0.02707818	25.8099419	74.1900581	No FPE
Malawi	3704.6445	597.994148	434.252489	2672.39787	0	27.8635814	72.1364186	No FPE
Malaysia	33069.255	13569.1432	11980.446	3705.6312	3814.03466	77.260855	22.739145	No FPE
Mali	4342.26767	805.082954	940.894984	2596.28973	0	40.2088971	59.7911029	No FPE
Malta	98602.9819	38992.9519	57450.0698	2159.96025	0	97.8094372	2.19056281	No FPE
Mauritania	6807.38859	1756.62688	2609.74144	1996.26212	444.758148	64.1416053	35.8583947	No FPE
Mauritius	34205.4344	10396.3486	12497.0291	11312.0568	0	66.9290656	33.0709344	No FPE
Mexico	60375.8351	18303.2244	30440.4158	7279.10364	4353.09126	80.7336911	19.2663089	No FPE
Mongolia	14649.4863	4897.92664	-	11318.7201	1165.83655	14.7781947	85.2218053	No FPE
Morocco	14256.9601	4593.55439	7530.76913	2093.39985	39.2367708	85.0414352	14.9585648	No FPE
Mozambique	2964.78638	415.204609	557.523086	1991.44634	0.61233634	32.8093688	67.1906312	No FPE
Namibia	26786.7082	6026.29244	14331.3102	6093.33178	335.773719	75.9988967	24.0011033	No FPE
Nepal	3557.29321	594.015432	596.863971	2366.4138	0	33.4771225	66.5228775	No FPE
Netherlands	241186.206	90329.4605	137276.53	9291.49983	4288.71484	94.3694066	5.63059344	No FPE
New Zealand	207023.029	66905.2947	85648.5389	51737.2892	2731.90583	73.6893063	26.3106937	No FPE
Nicaragua	10693.0762	2373.92494	2298.5797	6013.63931	6.93220359	43.6965432	56.3034568	FPE
Niger	3273.21053	468.271853	765.172384	2038.974	0.7922956	37.6830096	62.3169904	No FPE
Nigeria	11756.2561	1482.54327	1081.69917	5854.95145	3337.06221	21.8117266	78.1882734	No FPE
Norway	418777.356	163303.354	193990.587	18425.092	43058.3225	85.3183527	14.6816473	No FPE
Oman	91289.8995	19381.5961	32055.1966	6037.91955	33815.1872	56.3444511	43.6555489	FPE
Pakistan	7209.31217	1268.65261	2003.93055	3760.10187	176.627142	45.3938335	54.6061665	FPE
Panama	32892.0678	9746.20104	13847.3058	9298.56101	0	71.7300807	28.2699193	No FPE
Papua New Guinea	12178.9649	2476.95442	1325.38796	5995.88546	2380.73709	31.2205709	68.7794291	No FPE
Peru	21523.1641	7373.23701	10123.5159	3493.49674	532.91449	81.2926612	18.7073388	No FPE
Philippines	10001.828	2942.94009	4267.65226	2710.80902	80.4266266	72.092745	27.907255	No FPE
Portugal	126836.068	48599.9907	72334.9185	5863.19061	37.9686792	95.3474123	4.65258767	No FPE
Rwanda	3452.01416	607.289086	897.710396	1946.3149	0.69977937	43.5977205	56.4022795	FPE
Saudi Arabia	133727.272	39266.3721	11249.264	14218.4955	68993.1402	37.775119	62.224881	No FPE
Senegal	6842.57999	1126.76615	3199.4541	2513.81002	2.54972503	63.2249861	36.7750139	No FPE
Seychelles	74635.7105	25859.924	46460.6905	2315.09606	0	96.8981389	3.10186109	No FPE
Sierra Leone	2649.07355	415.209447	753.684488	1401.14386	79.0357559	44.1246312	55.8753688	FPE
Singapore	117916.203	69795.6483	48117.3923	3.16244795	0	99.9973181	0.00268195	No FPE
South Africa	44819.0738	13030.9524	17984.4549	12258.9586	1544.70794	69.2013571	30.7986429	No FPE
Spain	162086.782	61033.5908	93603.887	7402.56396	46.7401739	95.4041261	4.59587392	No FPE
Sri Lanka	9260.5951	2343.83942	3488.36586	3428.33732	0.05249468	62.9787311	37.0212689	No FPE
St. Kitts and Nevis	71965.8693	33200.8086	25971.8166	12793.2441	0	82.2231786	17.7768214	No FPE
Country	Total	Produced Capital	Human Capital	Renewable Resources	Non-Renewable Resources	Country 1 %	Country 2 %	FPE

Distribution of wealth instruments and FPE in 1995

Country	Total	Produced Capital	Human Capital	Renewable Resources	Non-Renewable Resources	Country 1 %	Country 2 %	FPE
St. Lucia	37779.0537	12283.667	25487.7898	7.59693046	0	99.9798912	0.02010884	No FPE
St. Vincent and the Grenadines	25810.4005	8302.54978	13987.6258	3520.225	0	86.3612152	13.6387848	No FPE
Sudan	11115.9833	970.129029	-	10354.8818	0.66480757	6.84093024	93.1590698	No FPE
			209.692365					
Swaziland	28370.4126	5943.31809	6165.52058	16230.0939	31.4800584	42.6812216	57.3187784	FPE
Sweden	247007.826	85513.5311	145414.3	15920.4505	159.544304	93.4900869	6.5099131	No FPE
Switzerland	346174.892	168525.814	161954.516	15694.3596	0.20279341	95.466291	4.53370905	No FPE
Syrian Arab Republic	15090.3837	3734.69694	3784.74426	4705.05624	2865.88622	49.8293574	50.1706426	FPE
Thailand	18786.439	7663.15377	6029.32493	4954.60221	139.358092	72.8849076	27.1150924	No FPE
Togo	4443.19467	982.646679	1332.79242	2127.75556	0	52.1120337	47.8879663	FPE
Tonga	52373.53	5248.72986	-	50619.6516	0	3.34878791	96.6512121	No FPE
			3494.85141					
Trinidad and Tobago	58537.5888	20684.0571	20065.1987	4418.93909	13369.3938	69.6121188	30.3878812	No FPE
Tunisia	18661.5284	6551.55011	9090.91549	2459.05421	560.008593	83.821996	16.178004	No FPE
Uganda	3546.22928	294.566279	473.214412	2778.44859	0	21.6506218	78.3493782	No FPE
United Arab Emirates	269937.934	97413.8501	34823.3599	3889.91764	133810.806	48.9880055	51.0119945	FPE
United Kingdom	231032.112	71219.1888	153034.304	5040.39539	1738.22426	97.0659405	2.93405951	No FPE
United States	271800.786	81085.003	177725.536	11388.9343	1601.31331	95.2206733	4.77932672	No FPE
Uruguay	39749.5516	9208.47457	25336.2925	5204.78455	0	86.9060547	13.0939453	No FPE
Venezuela, RB	59405.0518	16445.2908	11665.3136	8518.90326	22775.5441	47.3202254	52.6797746	FPE
Zambia	6984.03089	1370.19095	2130.69936	3017.3312	465.809376	50.1270737	49.8729263	FPE
Zimbabwe	3999.73209	881.29591	1479.30438	1338.24566	300.886148	59.0189601	40.9810399	FPE

Source: The World Bank wealth accounting database, Author's calculations

Distribution of wealth instruments and FPE in 2000

Country	Total	Produced Capital	Human Capital	Renewable Resources	Non-Renewable Resources	Country 1 %	Country 2 %	FPE
Albania	21 018	5 696	7762.1594	7 544	16	64.0327815	35.9672185	No FPE
Algeria	26 585	10 518	4732.53979	3 289	8 045	57.3657538	42.6342462	FPE
Argentina	37 537	10 949	20837.9308	4 633	1 117	84.6817556	15.3182444	No FPE
Armenia	11 629	3 617	4309.4752	3 664	38	68.1619476	31.8380524	No FPE
Australia	268 070	98 670	127207.337	32 272	9 921	84.2604816	15.7395184	No FPE
Austria	273 818	106 138	155798.589	11 563	319	95.6606549	4.33934507	No FPE
Azerbaijan	9 399	2 534	1326.87585	2 537	3 002	41.072345	58.927655	FPE
Bahrain	134 719	40 782	36524.9192	932	56 480	57.3836962	42.6163038	FPE
Bangladesh	3 505	786	1526.87118	1 124	68	65.9847709	34.0152291	No FPE
Belarus	24 577	8 712	5850.20083	9 597	418	59.2510171	40.7489829	FPE
Belgium	243 369	90 875	144909.579	7 583	0	96.8838908	3.11610925	No FPE
Belize	42 221	8 613	11289.48	22 318	0	47.1394796	52.8605204	FPE
Benin	7 351	944	1455.99278	4 938	13	32.6548586	67.3451414	No FPE
Bhutan	14 498	4 208	-	10 797	27	25.3417157	74.6582843	No FPE
			533.857893					
Bolivia	12 449	2 082	3207.97188	6 378	781	42.4927757	57.5072243	FPE
Botswana	28 389	13 487	9930.46714	4 718	253	82.4890739	17.5109261	No FPE
Brazil	43 917	11 406	19193.6683	12 501	817	69.6750306	30.3249694	No FPE
Brunei Darussalam	204 824	81 387	-	10 249	123 185	34.8542592	65.1457408	No FPE
			9996.85048					
Country	Total	Produced Capital	Human Capital	Renewable Resources	Non-Renewable Resources	Country 1 %	Country 2 %	FPE

Distribution of wealth instruments and FPE in 2000

Country	Total	Produced Capital	Human Capital	Renewable Resources	Non-Renewable Resources	Country 1 %	Country 2 %	FPE
Bulgaria	29 761	9 812	10180.5238	9 400	368	67.1770392	32.8229608	No FPE
Burkina Faso	5 207	873	1204.0503	3 130	0	39.884983	60.115017	No FPE
Burundi	2 048	211	145.095313	1 690	1	17.4054655	82.5945345	No FPE
Cameroon	10 763	2 407	3119.74576	4 559	679	51.3426453	48.6573547	FPE
Canada	260 007	81 311	138930.932	32 578	7 187	84.706197	15.293803	No FPE
Central African Republic	8 440	597	-	8 382	0	0.68394075	99.3160592	No FPE
Chad	6 407	610	820.908253	4 977	0	22.3312494	77.6687506	No FPE
Chile	55 362	16 289	25841.558	8 547	4 684	76.1004107	23.8995893	No FPE
China	9 974	3 796	2414.82794	3 416	347	62.2743913	37.7256087	No FPE
Colombia	29 532	6 953	12277.1264	9 337	965	65.1148561	34.8851439	No FPE
Comoros	7 730	1 799	3663.20588	2 268	0	70.6649667	29.3350333	No FPE
Congo, Dem. Rep.	2 648	248	-	2 400	71	6.67041566	93.3295843	No FPE
Congo, Rep.	15 855	5 367	71.8398422	4 661	9 648	9.74897933	90.2510207	No FPE
Costa Rica	37 620	8 597	18416.5211	10 606	0	71.8079008	28.1920992	No FPE
Côte d'Ivoire	10 079	1 684	3465.21681	4 739	190	51.0900384	48.9099616	FPE
Croatia	66 887	16 706	40937.4981	8 021	1 223	86.1803626	13.8196374	No FPE
Cyprus	172 584	56 763	103660.227	12 096	66	92.9533276	7.04667237	No FPE
Czech Republic	85 000	38 824	38736.1671	7 385	55	91.2471897	8.75281029	No FPE
Denmark	340 467	118 137	199126.541	18 802	4 402	93.1847274	6.81527255	No FPE
Dominica	43 666	13 772	16797.78	13 096	0	70.0086664	29.9913336	No FPE
Dominican Republic	28 212	6 910	16931.7719	4 173	197	84.5097008	15.4902992	No FPE
Ecuador	36 675	6 643	3004.93566	22 752	4 275	26.3055861	73.6944139	No FPE
Egypt, Arab Rep.	10 901	2 869	5200.78642	2 070	761	74.0294936	25.9705064	No FPE
El Salvador	23 681	4 733	14640.396	4 308	0	81.8087831	18.1912169	No FPE
Ethiopia	1 934	259	459.255587	1 216	0	37.1362262	62.8637738	No FPE
Fiji	37 072	8 200	6720.73836	21 777	374	40.2485634	59.7514366	No FPE
Finland	272 809	91 747	145619.121	35 391	52	87.0080064	12.9919936	No FPE
France	258 601	87 325	157877.951	13 333	65	94.8192153	5.18078467	No FPE
Gabon	71 254	26 004	-	11 218	34 275	36.1529162	63.8470838	No FPE
Gambia, The	3 175	680	243.961255	1 158	0	63.5369326	36.4630674	No FPE
Georgia	11 891	4 878	1337.23166	3 253	56	72.1666934	27.8333066	No FPE
Germany	257 022	97 146	3703.2383	8 438	263	96.6146916	3.38530836	No FPE
Ghana	6 327	903	151174.935	4 092	4	35.26856	64.73144	No FPE
Greece	175 924	66 139	1328.69219	12 522	54	92.85127	7.14872998	No FPE
Grenada	41 755	18 547	97208.7866	2 541	0	93.9133259	6.08667407	No FPE
Guatemala	25 245	4 619	20666.2517	12 040	246	51.3359105	48.6640895	FPE
Guinea	4 446	808	8340.26309	2 319	246	42.33101	57.66899	FPE
Guinea-Bissau	4 630	821	1074.45746	3 227	0	30.30215	69.69785	No FPE
Guyana	24 895	4 165	582.253507	22 672	735	5.97434587	94.0256541	No FPE
Haiti	5 931	1 671	-2677.2765	1 688	0	71.5441367	28.4558633	No FPE
Honduras	14 090	3 796	2572.90388	6 167	29	56.0302593	43.9697407	FPE
Hong Kong, China	145 758	72 386	4098.06008	8	0	99.9945126	0.00548736	No FPE
Hungary	76 618	31 645	73364.6512	8 246	759	88.2463182	11.7536818	No FPE
Iceland	381 358	120 904	149510.067	15 735	0	95.8738864	4.12611359	No FPE
India	6 291	1 446	244718.407	3 065	187	48.3168826	51.6831174	FPE
Indonesia	12 762	3 645	1594.07223	5 438	951	49.9444644	50.0555356	FPE
Iran, Islamic Rep.	22 637	8 544	2729.17191	6 130	8 145	36.9396631	63.0603369	No FPE
Ireland	249 400	82 072	181.469558	17 247	572	92.8553914	7.14460856	No FPE
Israel	147 285	46 968	149510.067	4 478	3	96.9577494	3.04225065	No FPE
Italy	234 369	85 889	149510.067	9 485	439	95.765751	4.23424905	No FPE
Country	Total	Produced Capital	Human Capital	Renewable Resources	Non-Renewable Resources	Country 1 %	Country 2 %	FPE

Distribution of wealth instruments and FPE in 2000

Country	Total	Produced Capital	Human Capital	Renewable Resources	Non-Renewable Resources	Country 1 %	Country 2 %	FPE
Jamaica	39 031	12 391	18901.4325	6 568	1 171	80.172721	19.827279	No FPE
Japan	269 629	134 953	130042.811	4 611	21	98.2819294	1.71807063	No FPE
Jordan	20 871	6 593	12234.6996	1 992	52	90.210016	9.78998401	No FPE
Kenya	7 064	1 325	1808.54768	3 930	0	44.3602495	55.6397505	FPE
Korea, Rep.	102 696	47 402	52315.4976	2 976	3	97.0992815	2.90071851	No FPE
Kuwait	260 927	55 262	36515.4409	1 488	167 662	35.1736303	64.8263697	No FPE
Kyrgyz Republic	5 942	1 307	1049.64619	3 546	40	39.6611516	60.3388484	No FPE
Latvia	46 869	19 769	16926.1903	10 173	0	78.2939254	21.7060746	No FPE
Lesotho	10 364	4 349	4921.60165	1 093	0	89.4550694	10.5449306	No FPE
Liberia	3 620	132	895.753223	2 512	80	28.3912981	71.6087019	No FPE
Lithuania	51 991	18 896	24322.864	8 608	163	83.1284907	16.8715093	No FPE
Luxembourg	396 229	177 730	206943.344	11 555	0	97.0837162	2.91628382	No FPE
Macao, China	88 935	47 271	41664.381	0	0	100	0	No FPE
Macedonia, FYR	26 636	7 337	13805.2224	5 494	0	79.375157	20.624843	No FPE
Madagascar	3 631	448	977.288307	2 206	0	39.2478102	60.7521898	No FPE
Malawi	3 423	499	708.463376	2 215	0	35.2899893	64.7100107	No FPE
Malaysia	36 185	16 538	10235.6522	4 243	5 168	73.9903605	26.0096395	No FPE
Maldives	12 599	6 013	5615.15286	970	0	92.2986362	7.70136381	No FPE
Mali	5 052	859	999.095334	3 194	0	36.7729197	63.2270803	No FPE
Malta	120 390	45 666	70025.3145	4 699	0	96.0968836	3.90311645	No FPE
Mauritania	7 683	1 292	2838.71494	2 753	799	53.7658416	46.2341584	FPE
Mauritius	42 060	12 814	14365.4915	14 880	0	64.6210372	35.3789628	No FPE
Mexico	64 803	20 175	35875.8147	5 192	3 560	86.4942733	13.5057267	No FPE
Moldova	10 350	4 163	719.511868	5 467	0	47.179859	52.820141	FPE
Mongolia	12 709	3 947	702.306796	7 265	795	36.583678	63.416322	No FPE
Morocco	15 070	4 929	7185.34881	2 865	90	80.3895855	19.6104145	No FPE
Mozambique	3 209	542	851.19383	1 816	0	43.4148724	56.5851276	FPE
Namibia	26 112	6 648	15010.3216	4 343	111	82.9436951	17.0563049	No FPE
Nepal	4 042	723	587.851216	2 732	0	32.424109	67.575891	No FPE
Netherlands	276 874	101 694	160768.556	9 399	5 012	94.7949224	5.20507757	No FPE
New Zealand	230 014	70 193	91132.7734	65 523	3 164	70.1375915	29.8624085	No FPE
Nicaragua	11 461	2 810	3686.66187	4 963	2	56.680758	43.319242	FPE
Niger	3 287	359	790.719348	2 137	0	34.9666104	65.0333896	No FPE
Nigeria	9 439	1 441	740.160046	4 184	3 074	23.1033571	76.8966429	No FPE
Norway	465 420	176 753	198516.199	26 612	63 539	80.6300556	19.3699444	No FPE
Oman	96 321	20 609	29921.0162	5 931	39 860	52.4599482	47.5400518	FPE
Pakistan	7 471	1 366	1994.33074	3 897	214	44.9757942	55.0242058	FPE
Panama	37 427	11 745	18032.5448	7 650	0	79.5611323	20.4388677	No FPE
Papua New Guinea	13 144	2 459	-	8 460	2 244	18.568041	81.431959	No FPE
Peru	23 447	7 456	10941.9371	4 523	526	78.4655388	21.5344612	No FPE
Philippines	10 939	2 868	4300.33438	3 733	38	65.5248286	34.4751714	No FPE
Poland	59 906	17 846	31305.9349	10 429	326	82.0477257	17.9522743	No FPE
Portugal	148 560	55 859	86050.211	6 648	3	95.5234265	4.47657353	No FPE
Romania	37 833	13 279	13776.8074	8 396	2 382	71.5132745	28.4867255	No FPE
Russian Federation	48 730	18 614	1602.12768	14 372	14 143	41.485027	58.514973	FPE
Rwanda	3 294	436	751.787441	2 106	0	36.069913	63.930087	No FPE
Saudi Arabia	125 056	35 243	15357.8782	12 609	61 846	40.4626837	59.5373163	No FPE
Senegal	7 265	1 219	3240.58875	2 796	10	61.3841652	38.6158348	No FPE
Seychelles	90 807	32 539	56014.0819	2 254	0	97.517835	2.48216499	No FPE
Sierra Leone	2 304	271	717.664909	1 315	1	42.8992632	57.1007368	FPE
Singapore	135 676	83 714	51959.2012	2	0	99.9982862	0.00171383	No FPE
Slovak Republic	64 528	28 991	27739.9543	7 721	76	87.9167056	12.0832944	No FPE
South Africa	40 682	11 330	20265.2818	8 063	1 024	77.6649002	22.3350998	No FPE
Spain	188 171	69 091	108500.995	10 560	18	94.3781061	5.62189393	No FPE
Country	Total	Produced Capital	Human Capital	Renewable Resources	Non-Renewable Resources	Country 1 %	Country 2 %	FPE

Distribution of wealth instruments and FPE in 2000

Country	Total	Produced Capital	Human Capital	Renewable Resources	Non-Renewable Resources	Country 1 %	Country 2 %	FPE
Sri Lanka	9 887	2 863	4416.20961	2 608	0	73.6225031	26.3774969	No FPE
St. Kitts and Nevis	86 800	40 557	30953.624	15 289	0	82.3855628	17.6144372	No FPE
St. Lucia	41 527	14 839	26675.1923	14	0	99.96725	0.03274999	No FPE
St. Vincent and the Grenadines	29 714	10 206	16209.426	3 299	0	88.8979017	11.1020983	No FPE
Sudan	9 591	1 098	1096.45574	7 240	156	22.882483	77.117517	No FPE
Swaziland	31 328	5 752	4425.80724	21 131	18	32.4891593	67.5108407	No FPE
Sweden	276 992	87 945	168369.522	20 586	92	92.5350273	7.46497268	No FPE
Switzerland	355 785	169 000	173276.228	13 509	0	96.2031586	3.79684143	No FPE
Syrian Arab Republic	13 667	3 690	4039.97651	2 906	3 031	56.5604575	43.4395425	FPE
Tajikistan	3 907	1 441	437.088344	2 014	16	48.0569472	51.9430528	FPE
Thailand	22 653	8 716	4503.75419	9 107	326	58.3563748	41.6436252	FPE
Togo	4 133	784	1694.36769	1 643	11	59.9641787	40.0358213	No FPE
Tonga	48 827	5 384	945.560868	42 497	0	12.963153	87.036847	No FPE
Trinidad and Tobago	70 406	22 126	27214.2762	1 046	20 020	70.0802909	29.9197091	No FPE
Tunisia	21 985	7 437	10782.6264	3 198	567	82.8742795	17.1257205	No FPE
Turkey	47 399	12 341	26672.3696	8 251	135	82.3075967	17.6924033	No FPE
Uganda	5 050	436	100.204399	4 515	0	10.6094441	89.3905559	No FPE
Ukraine	16 947	7 877	1834.8578	6 250	985	57.3079284	42.6920716	FPE
United Arab Emirates	244 400	84 972	47965.6071	4 642	106 821	54.3934688	45.6065312	FPE
United Kingdom	262 161	76 336	178429.039	4 722	2 673	97.1791225	2.82087747	No FPE
United States	309 980	91 254	204327.423	12 811	1 587	95.3549561	4.6450439	No FPE
Uruguay	41 826	9 639	26416.101	5 771	0	86.20239	13.79761	No FPE
Uzbekistan	5 275	1 491	553.848252	1 543	1 688	38.756071	61.243929	No FPE
Vanuatu	25 312	5 691	5562.82609	14 059	0	44.4594314	55.5405686	FPE
Venezuela, RB	54 250	16 058	11639.3164	6 183	20 370	51.0555056	48.9444944	FPE
Zambia	7 173	1 188	2158.78904	3 676	149	46.6579481	53.3420519	FPE
Zimbabwe	4 284	950	1336.08324	1 799	199	53.3613115	46.6386885	FPE

Source: The World Bank wealth accounting database, Author's calculations

Distribution of wealth instruments and FPE in 2005

Country	Total	Produced Capital	Human Capital	Renewable Resources	Non-Renewable Resources	Country 1 %	Country 2 %	FPE
Albania	26 961	6 975	14917.8907	5 067	1	81.2012448	18.7987552	No FPE
Algeria	27 672	11 046	811.402547	2 522	13 293	42.8490953	57.1509047	FPE
Angola	15 705	2 897	-	2 255	11 052	15.2689776	84.7310224	No FPE
Argentina	39 219	10 815	18137.1088	7 540	2 727	73.8216634	26.1783366	No FPE
Armenia	15 372	4 185	8047.99539	3 023	116	79.581614	20.418386	No FPE
Australia	290 746	111 671	139097.115	19 650	20 328	86.2496896	13.7503104	No FPE
Austria	286 320	112 799	164456.47	8 498	566	96.83411	3.16588999	No FPE
Azerbaijan	16 288	4 535	70.0678805	2 489	9 194	28.2707109	71.7292891	No FPE
Bahrain	148 360	43 365	21333.9864	739	82 923	43.6090327	56.3909673	FPE
Bangladesh	4 143	1 007	1741.76451	1 204	190	66.347817	33.652183	No FPE
Belarus	27 455	9 812	11671.0654	5 199	773	78.2488612	21.7511388	No FPE
Belgium	264 859	98 822	161105.241	4 932	0	98.1376334	1.86236655	No FPE
Country	Total	Produced Capital	Human Capital	Renewable Resources	Non-Renewable Resources	Country 1 %	Country 2 %	FPE

Distribution of wealth instruments and FPE in 2005

Country	Total	Produced Capital	Human Capital	Renewable Resources	Non-Renewable Resources	Country 1 %	Country 2 %	FPE
Belize	45 914	9 258	12929.851	23 726	0	48.3253751	51.6746249	FPE
Benin	5 852	1 051	2175.20202	2 625	0	55.1397022	44.8602978	FPE
Bhutan	18 953	6 319	-	14 005	0	26.107501	73.892499	No FPE
			1370.72444					
Bolivia	12 328	2 000	2022.44253	6 114	2 191	32.6278585	67.3721415	No FPE
Botswana	36 469	20 988	10060.8247	4 439	982	85.1370784	14.8629216	No FPE
Brazil	45 953	11 330	19644.8129	12 657	2 321	67.4048681	32.5951319	No FPE
Brunei	204 208	73 831	-	10 059	172 958	10.3769444	89.6230556	No FPE
Darus-salam			52639.9229					
Bulgaria	33 641	10 079	18002.1974	5 004	556	83.4728443	16.5271557	No FPE
Burkina Faso	4 578	879	2359.39205	1 339	0	70.7446679	29.2553321	No FPE
Burundi	2 673	166	-	2 695	2	-	100.901013	No FPE
			189.697395			0.90101281		
Cameroon	11 180	2 343	3639.57289	4 288	910	53.5090651	46.4909349	FPE
Canada	276 113	89 811	149377.69	24 280	12 644	86.6271915	13.3728085	No FPE
Cape Verde	19 752	5 797	13036.383	919	0	95.3493573	4.65064273	No FPE
Central African Republic	6 580	515	203.660814	5 861	0	10.9210372	89.0789628	No FPE
Chad	5 780	1 308	-164.46648	2 406	2 231	19.7777375	80.2222625	No FPE
Chile	61 815	19 268	23677.1046	9 307	9 563	69.4736052	30.5263948	No FPE
China	13 241	6 017	3211.42923	3 209	804	69.6921359	30.3078641	No FPE
Colombia	29 395	7 127	14654.317	6 126	1 488	74.0978279	25.9021721	No FPE
Comoros	7 284	1 301	4217.08212	1 765	0	75.7620985	24.2379015	No FPE
Congo, Dem. Rep.	2 043	200	243.9898	1 522	77	21.7400719	78.2599281	No FPE
Congo, Rep.	15 261	4 639	-	2 863	11 816	3.81127981	96.1887202	No FPE
			4056.90486					
Costa Rica	41 746	10 703	21605.847	9 437	0	77.3947746	22.6052254	No FPE
Côte d'Ivoire	8 915	1 473	3455.42615	3 523	464	55.278993	44.721007	FPE
Croatia	81 605	25 231	50815.4215	3 637	1 923	93.1877979	6.81220209	No FPE
Czech Republic	97 561	44 254	48712.3098	4 264	332	95.2898143	4.71018573	No FPE
Denmark	363 283	130 827	212840.617	11 080	8 536	94.6003591	5.3996409	No FPE
Dominica	44 819	14 414	20011.7966	10 393	0	76.8113898	23.1886102	No FPE
Dominican Republic	32 890	8 041	20099.1527	4 332	418	85.5584227	14.4415773	No FPE
Ecuador	35 607	7 601	5551.96046	16 012	6 442	36.9399326	63.0600674	No FPE
Egypt, Arab Rep.	12 520	2 860	4989.63358	2 681	1 989	62.7000059	37.2999941	No FPE
El Salvador	25 328	5 201	16185.9962	3 941	0	84.4393212	15.5606788	No FPE
Ethiopia	2 199	324	752.04727	1 120	2	48.9393169	51.0606831	FPE
Fiji	29 079	8 693	8769.68814	11 232	384	60.0535388	39.9464612	No FPE
Finland	281 427	96 566	165640.057	19 088	132	93.170335	6.82966498	No FPE
France	275 625	93 619	173396.881	8 538	71	96.8764731	3.1235269	No FPE
Gabon	62 966	23 418	-	7 455	34 610	33.1943701	66.8056299	No FPE
			2516.75015					
Gambia, The	3 571	758	1582.66505	1 230	0	65.5499756	34.4500244	No FPE
Georgia	15 329	5 128	6867.34512	3 247	87	78.2526078	21.7473922	No FPE
Germany	261 314	98 285	157313.177	5 181	535	97.8126273	2.18737265	No FPE
Ghana	5 996	1 237	2101.6984	2 653	5	55.6763257	44.3236743	FPE
Greece	199 793	74 237	117575.738	7 575	405	96.005998	3.99400204	No FPE
Grenada	46 593	23 375	21135.1932	2 083	0	95.5285723	4.4714277	No FPE
Guatemala	29 906	5 370	7844.99409	16 361	330	44.1874573	55.8125427	FPE
Guinea	4 125	777	1408.03936	1 713	226	52.9840556	47.0159444	FPE
Guinea-Bissau	3 279	604	596.997153	2 078	0	36.6255717	63.3744283	No FPE
Guyana	24 271	4 106	-	21 233	649	9.84400086	90.1559991	No FPE
			1717.17699					
Haiti	5 776	1 761	2756.50486	1 258	0	78.2151659	21.7848341	No FPE
Honduras	19 689	4 140	3537.00194	11 964	48	38.9908477	61.0091523	No FPE
Country	Total	Produced Capital	Human Capital	Renewable Resources	Non-Renewable Resources	Country 1 %	Country 2 %	FPE

Distribution of wealth instruments and FPE in 2005

Country	Total	Produced Capital	Human Capital	Renewable Resources	Non-Renewable Resources	Country 1 %	Country 2 %	FPE
Hong Kong, China	156 880	77 653	79218.2568	10	0	99.9939274	0.00607263	No FPE
Hungary	92 003	35 162	50866.5697	5 172	803	93.5062861	6.49371385	No FPE
Iceland	437 517	137 470	287684.267	12 363	0	97.1743333	2.8256667	No FPE
India	6 831	1 980	2146.061	2 351	353	60.4134331	39.5865669	No FPE
Indonesia	12 997	3 968	4103.32717	3 452	1 473	62.1014156	37.8985844	No FPE
Iran, Islamic Rep.	29 911	10 516	1461.37521	3 946	13 987	40.0445353	59.9554647	No FPE
Ireland	298 516	112 374	174952.931	10 899	290	96.2516685	3.74833153	No FPE
Israel	152 475	47 232	100400.964	4 589	253	96.8240334	3.17596663	No FPE
Italy	243 323	89 860	145961.223	6 977	525	96.916778	3.08322198	No FPE
Jamaica	42 424	14 450	22601.272	4 393	979	87.3375847	12.6624153	No FPE
Japan	281 554	135 866	143593.182	2 048	47	99.2561062	0.74389379	No FPE
Jordan	25 787	6 550	16546.7077	2 617	74	89.5679317	10.4320683	No FPE
Kenya	6 460	1 298	2422.58928	2 738	2	57.5951926	42.4048074	FPE
Korea, Rep.	129 734	58 636	68455.6381	2 616	26	97.9637588	2.0362412	No FPE
Kuwait	268 568	58 115	-	1 099	212 013	20.6490367	79.3509633	No FPE
			2657.79243					
Kyrgyz Republic	6 612	1 210	2410.47161	2 923	69	54.7538854	45.2461146	FPE
Lao PDR	6 708	1 208	1055.20357	4 444	0	33.7444999	66.2555001	No FPE
Latvia	64 683	23 260	34077.0333	7 346	0	88.642543	11.357457	No FPE
Lesotho	11 039	4 705	6008.76008	325	0	97.0564549	2.94354509	No FPE
Liberia	4 015	217	597.415764	3 201	0	20.279078	79.720922	No FPE
Lithuania	66 435	21 265	39155.0728	5 667	347	90.9471385	9.05286147	No FPE
Luxembourg	435 000	213 425	215482.798	6 092	0	98.5995556	1.4004444	No FPE
Macao, China	101 565	51 849	49715.5337	0	0	100	0	No FPE
Macedonia, FYR	28 725	8 018	17065.3446	3 642	0	87.3204873	12.6795127	No FPE
Madagascar	2 895	551	426.458841	1 918	0	33.7540564	66.2459436	No FPE
Malawi	2 424	528	726.529979	1 170	0	51.7397288	48.2602712	FPE
Malaysia	42 513	16 824	12939.3971	2 648	10 102	70.0096121	29.9903879	No FPE
Maldives	15 198	7 402	6806.6572	990	0	93.4885683	6.51143166	No FPE
Mali	4 431	990	1534.05601	1 907	0	56.9718378	43.0281622	FPE
Malta	123 229	45 063	73882.647	4 283	0	96.5239476	3.4760524	No FPE
Mauritania	8 065	1 701	2349.06573	2 683	1 332	50.2159249	49.7840751	FPE
Mauritius	45 659	14 841	21439.7898	9 379	0	79.4596108	20.5403892	No FPE
Mexico	66 304	21 320	38342.8636	3 116	3 525	89.9833441	10.0166559	No FPE
Moldova	11 513	3 794	3570.68372	4 145	3	63.9712869	36.0287131	No FPE
Mongolia	10 871	3 675	1718.94994	4 291	1 186	49.6184579	50.3815421	FPE
Morocco	16 938	5 984	8505.35692	2 377	71	85.5464422	14.4535578	No FPE
Mozambique	3 334	708	1378.76393	1 130	118	62.5743135	37.4256865	No FPE
Namibia	29 757	8 280	16285.7833	4 960	231	82.555137	17.444863	No FPE
Nepal	4 128	828	837.028827	2 463	0	40.3354633	59.6645367	No FPE
Netherlands	292 905	109 658	170053.569	6 133	7 061	95.4956506	4.50434945	No FPE
New Zealand	239 465	76 281	110204.598	49 304	3 675	77.8761134	22.1238866	No FPE
Nicaragua	12 355	3 127	4497.91184	4 709	21	61.7170079	38.2829921	No FPE
Niger	2 846	386	1029.16333	1 430	0	49.7322432	50.2677568	FPE
Nigeria	8 925	1 698	1185.13191	2 101	3 940	32.3052032	67.6947968	No FPE
Norway	484 804	183 078	191563.64	10 456	99 706	77.2770205	22.7229795	No FPE
Oman	116 337	22 987	16215.5829	5 503	71 631	33.6975609	66.3024391	No FPE
Pakistan	7 540	1 449	2735.92642	2 888	467	55.5069573	44.4930427	FPE
Panama	41 186	11 672	21569.9154	7 944	0	80.7124242	19.2875758	No FPE
Papua New Guinea	10 545	2 547	-	5 950	2 618	18.7425438	81.2574562	No FPE
			570.212057					
Peru	24 919	7 160	11941.0026	4 770	1 047	76.6531638	23.3468362	No FPE
Philippines	11 281	2 745	5067.38466	3 329	139	69.2557285	30.7442715	No FPE
Poland	68 997	20 526	39576.4659	7 769	1 126	87.1089676	12.8910324	No FPE
Portugal	155 600	59 939	91457.0814	4 167	37	97.298184	2.70181603	No FPE
Romania	44 575	14 292	21225.1078	6 705	2 353	79.6797789	20.3202211	No FPE
Russian Federation	57 800	17 712	8771.11778	7 079	24 238	45.8184628	54.1815372	FPE
Country	Total	Produced Capital	Human Capital	Renewable Resources	Non-Renewable Resources	Country 1 %	Country 2 %	FPE

Distribution of wealth instruments and FPE in 2005

Country	Total	Produced Capital	Human Capital	Renewable Resources	Non-Renewable Resources	Country 1 %	Country 2 %	FPE
Rwanda	4 156	488	721.096338	2 947	0	29.0911631	70.9088369	No FPE
Saudi Arabia	131 779	33 000	1766.96752	10 392	86 620	26.3827497	73.6172503	No FPE
Senegal	7 037	1 520	3896.82337	1 615	6	76.9708064	23.0291936	No FPE
Seychelles	86 363	33 767	50742.0241	1 854	0	97.8528348	2.14716523	No FPE
Sierra Leone	2 592	251	978.046334	1 363	0	47.4256772	52.5743228	FPE
Singapore	140 752	81 405	59345.7804	2	0	99.9985896	0.00141039	No FPE
Slovak Republic	76 628	31 954	39694.6703	4 877	102	93.5020809	6.49791908	No FPE
South Africa	42 067	11 087	25256.3735	3 129	2 595	86.3944928	13.6055072	No FPE
Spain	208 724	82 194	119058.516	7 413	58	96.4206089	3.57939108	No FPE
Sri Lanka	11 447	3 371	6001.32728	2 074	0	81.8764069	18.1235931	No FPE
St. Kitts and Nevis	87 771	48 800	34576.2427	4 395	0	94.9931867	5.00681329	No FPE
St. Lucia	46 143	16 781	29337.3329	25	0	99.9464867	0.05351332	No FPE
St. Vincent and the Grenadines	33 303	12 183	18054.6276	3 065	0	90.7958238	9.20417624	No FPE
Sudan	10 074	1 495	1667.48293	5 357	1 554	31.3907146	68.6092854	No FPE
Swaziland	24 768	5 885	8302.75574	10 580	0	57.2824847	42.7175153	FPE
Sweden	298 285	92 488	190123.979	15 307	366	94.7456227	5.25437731	No FPE
Switzerland	357 352	165 561	182380.533	9 411	0	97.3664904	2.63350962	No FPE
Syrian Arab Republic	14 544	3 709	2925.1947	3 252	4 657	45.6179477	54.3820523	FPE
Tajikistan	4 313	1 093	1458.75963	1 735	27	59.1573455	40.8426545	FPE
Thailand	25 134	9 711	7613.84944	7 172	638	68.9273169	31.0726831	No FPE
Togo	3 723	794	1818.13276	1 106	5	70.1769737	29.8230263	No FPE
Tonga	45 089	5 440	6733.52262	32 916	0	26.9990632	73.0009368	No FPE
Trinidad and Tobago	88 373	24 826	18268.5252	792	44 486	48.7641592	51.2358408	FPE
Tunisia	26 321	8 420	13488.1499	3 361	1 051	83.234976	16.765024	No FPE
Turkey	54 528	13 895	35277.4874	5 148	208	90.1784816	9.82151836	No FPE
Uganda	4 737	585	779.401249	3 372	0	28.8126491	71.1873509	No FPE
Ukraine	19 723	7 250	5574.42513	4 929	1 970	65.0217938	34.9782062	No FPE
United Arab Emirates	233 074	72 873	39211.9265	2 878	118 111	48.0898832	51.9101168	FPE
United Kingdom	299 488	84 861	208364.746	3 178	3 085	97.908853	2.09114702	No FPE
United States	339 705	100 075	225808.531	10 343	3 478	95.9313002	4.06869978	No FPE
Uruguay	43 059	9 743	25028.0116	8 288	0	80.7520372	19.2479628	No FPE
Uzbekistan	7 796	1 543	-	2 287	5 365	1.8397535	98.1602465	No FPE
Vanuatu	18 530	5 267	1399.28527	6 951	0	62.490136	37.509864	No FPE
Venezuela, RB	54 399	15 863	6312.73617	6 477	24 090	43.8085244	56.1914756	FPE
Vietnam	6 992	1 851	1510.46962	2 747	884	48.0753444	51.9246556	FPE
Zambia	6 130	1 482	2505.79338	1 768	374	65.0611888	34.9388112	No FPE
Zimbabwe	3 705	827	913.375052	1 890	75	46.9636911	53.0363089	FPE

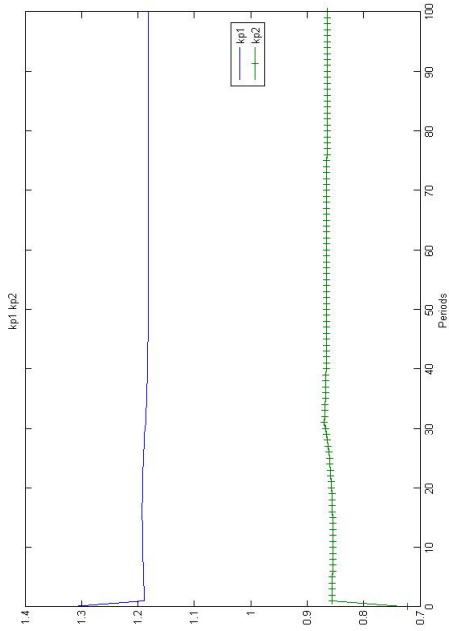
Source: *The World Bank wealth accounting database, Author's calculations*

APPENDIX E

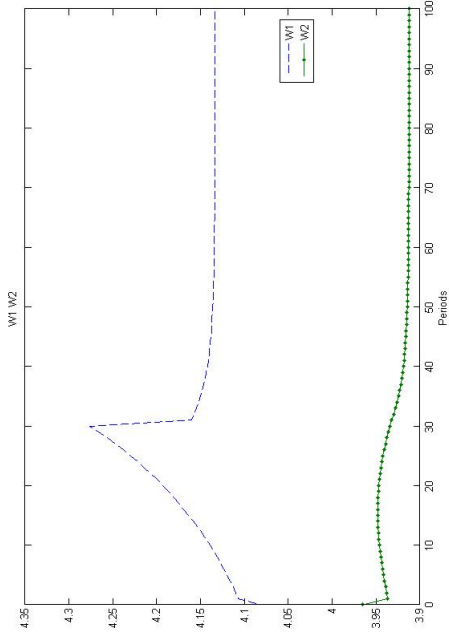
Diagrams of the simulations in chapter
3

Scenario 1 under SC (temporary shock)

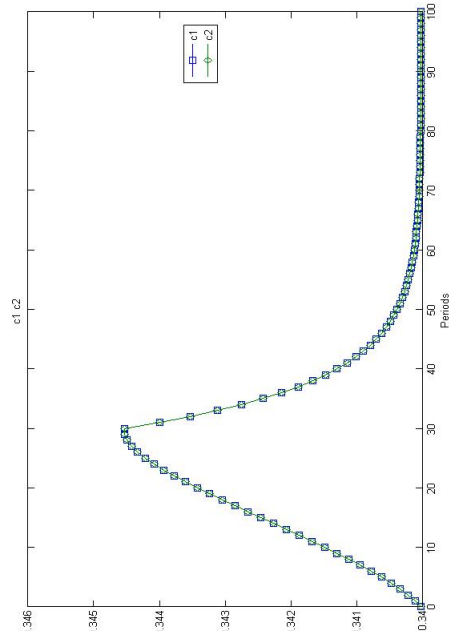
(a) Factor Endowments



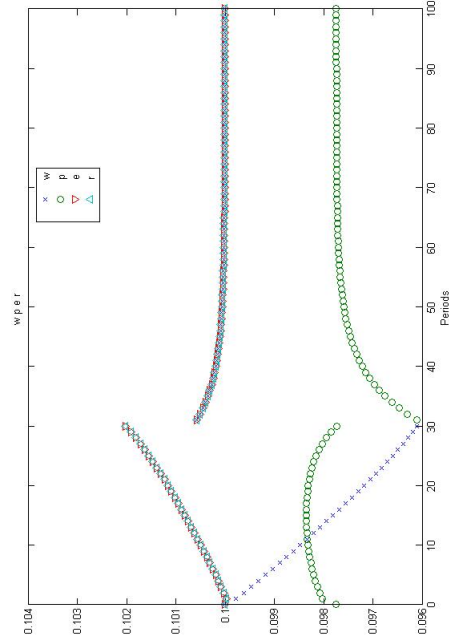
(b) Total Wealth



(c) Consumption Levels



(d) Factor Prices

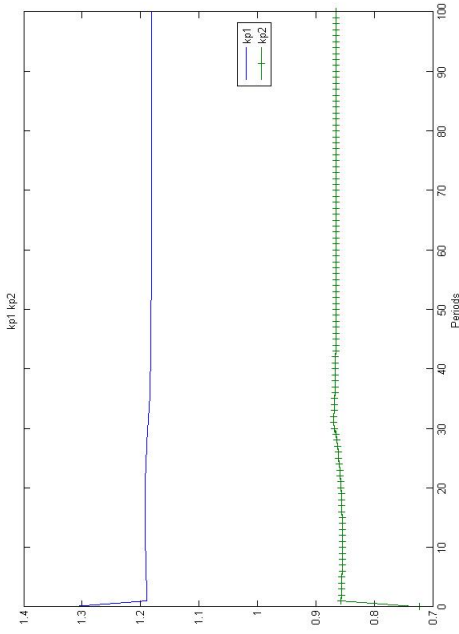


Simulations under the Structural Change (SC) hypothesis, scenarios in the Integrated Equilibrium (IE)

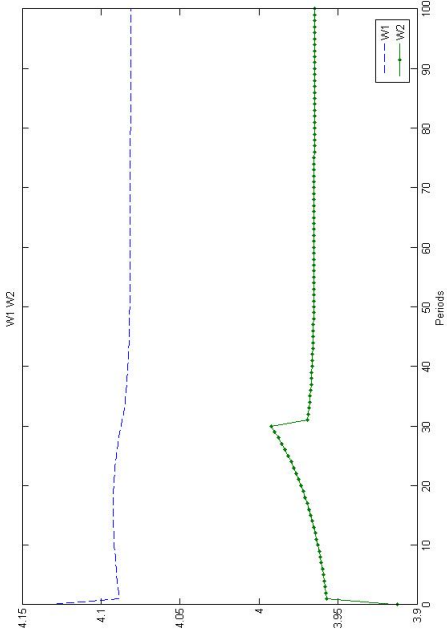
Source: Author's calculation

Scenario 2 under SC (temporary shock)

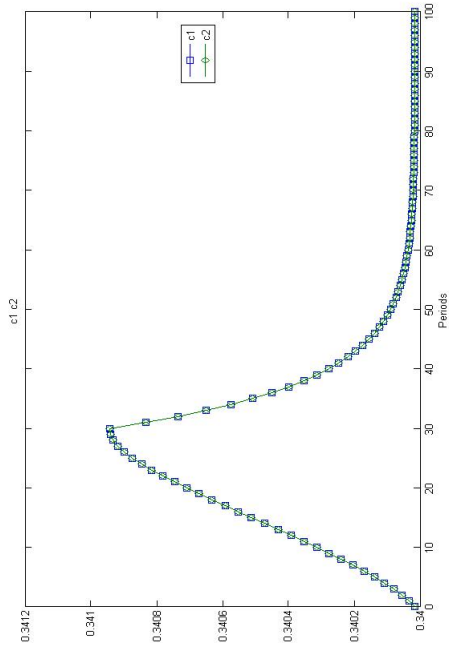
(a) Factor Endowments



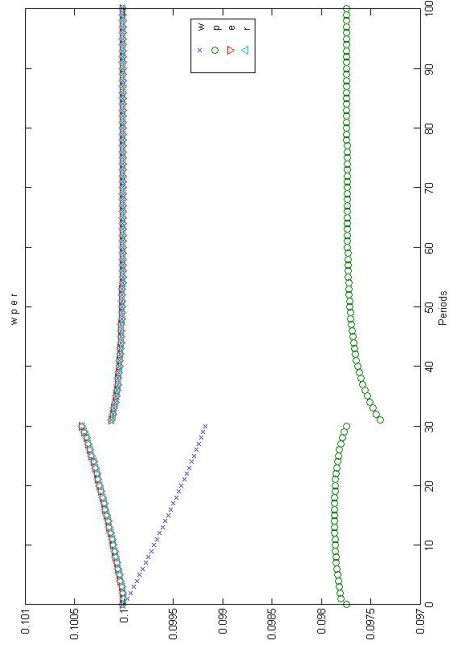
(b) Total Wealth



(c) Consumption Levels



(d) Factor Prices

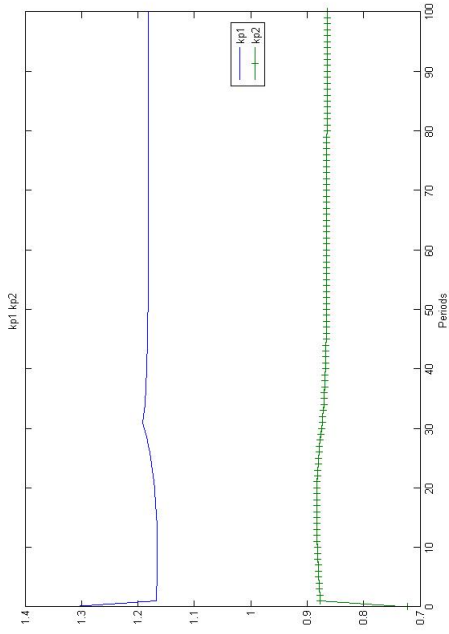


Simulations under the Structural Change (SC) hypothesis, scenarios in the Integrated Equilibrium (IE)

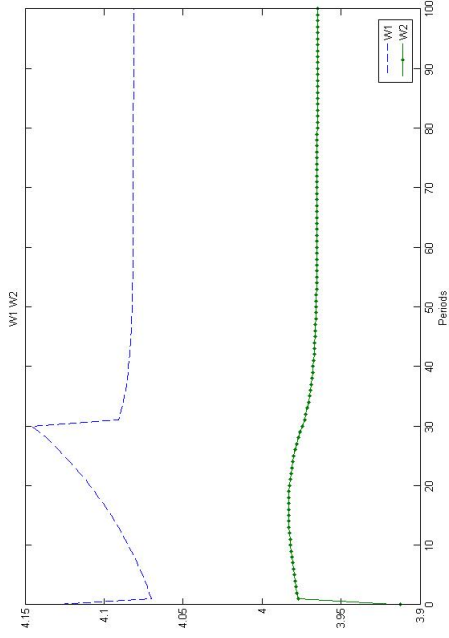
Source: Author's calculations

Scenario 3 under SC (temporary shock)

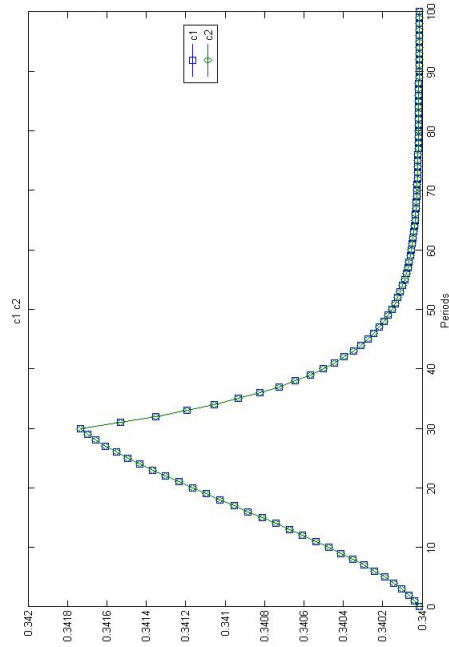
(a) Factor Endowments



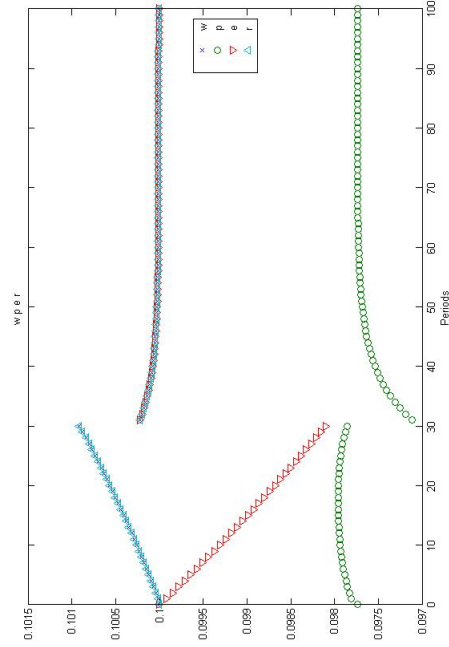
(b) Total Wealth



(c) Consumption Levels



(d) Factor Prices

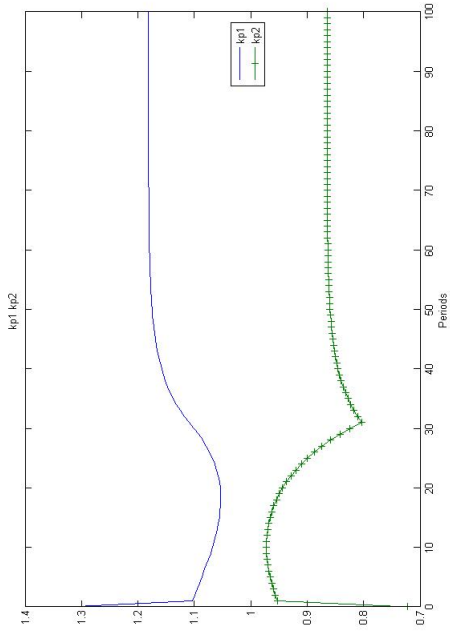


Simulations under the Structural Change (SC) hypothesis, scenarios in the Integrated Equilibrium (IE)

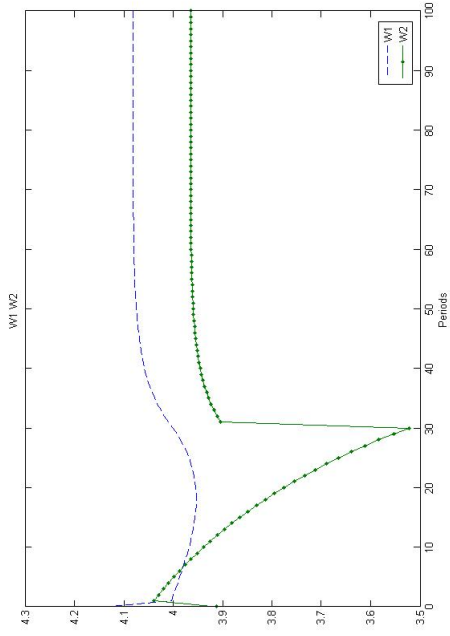
Source: Author's calculations

Scenario 4 under SC (temporary shock)

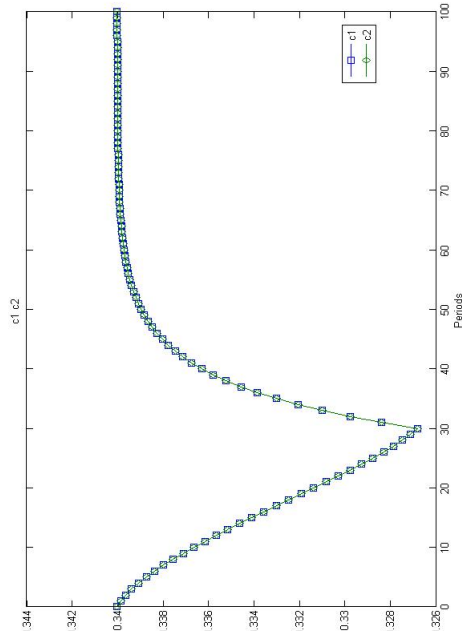
(a) Factor Endowments



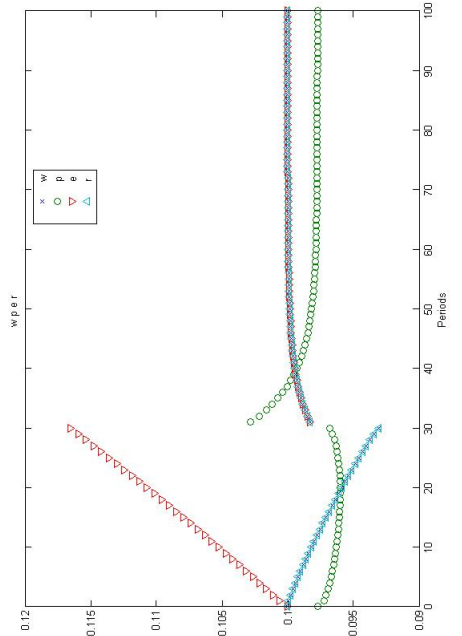
(b) Total Wealth



(c) Consumption Levels



(d) Factor Prices

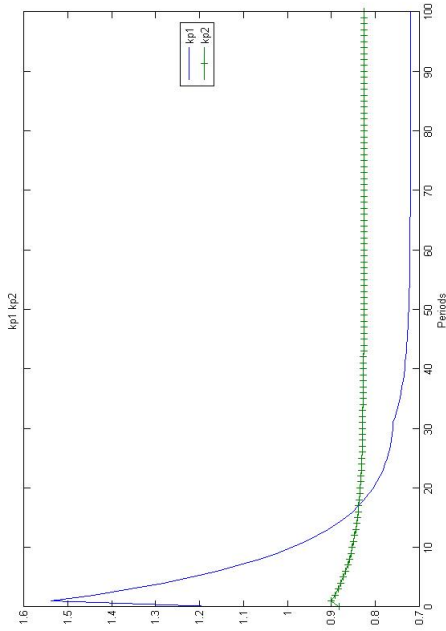


Simulations under the Structural Change (SC) hypothesis, scenarios in the Integrated Equilibrium (IE)

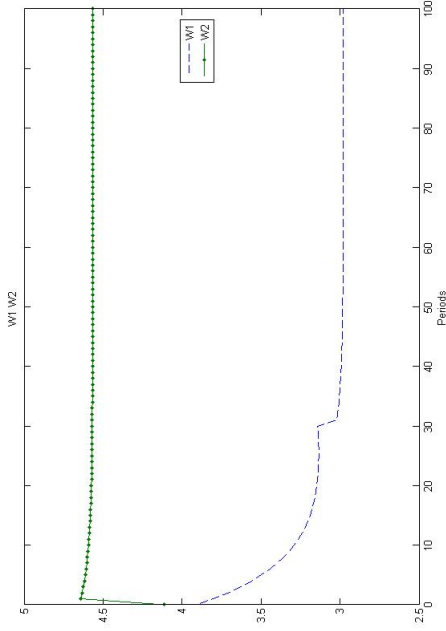
Source: Author's calculations

Scenario 1 under SC (temporary shock)

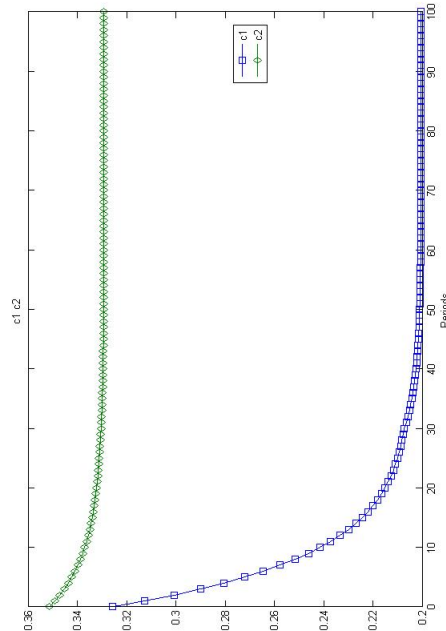
(a) Factor Endowments



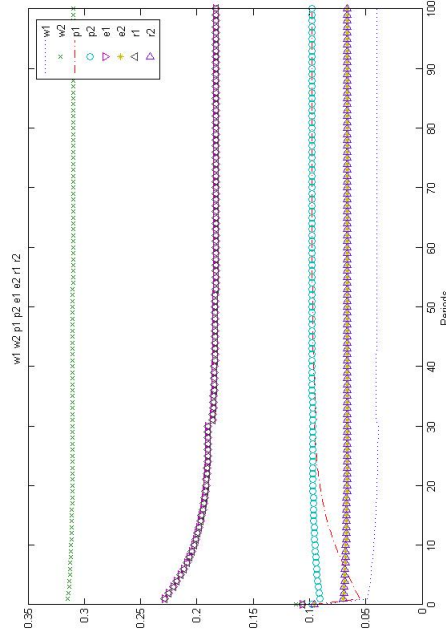
(b) Total Wealth



(c) Consumption Levels



(d) Factor Prices

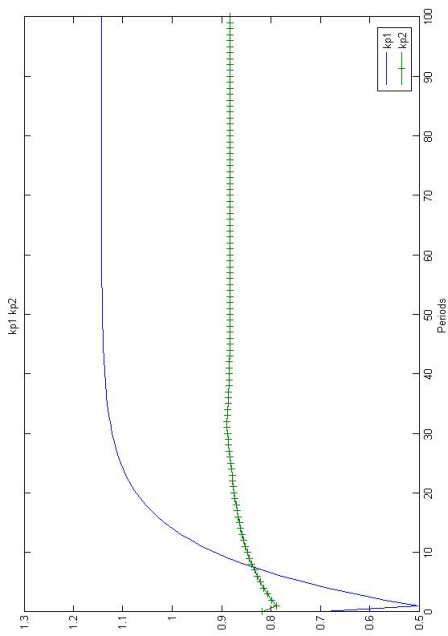


Simulations under the Structural Change (SC) hypothesis, scenarios in the Complete Specialisation (CS) equilibrium

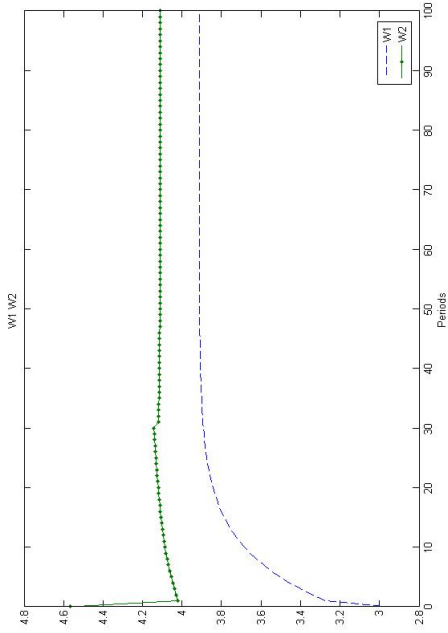
Source: Author's calculations

Scenario 2 under SC (temporary shock)

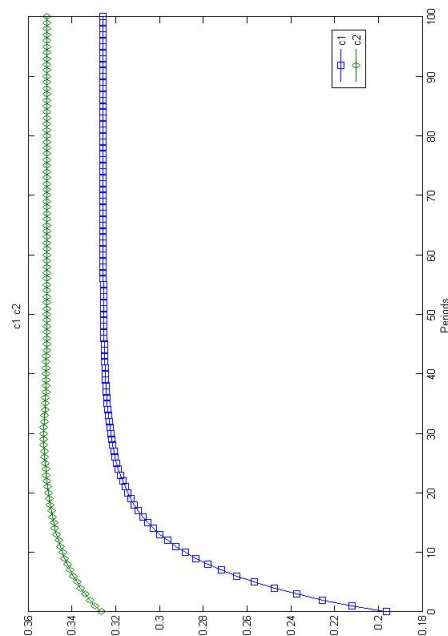
(a) Factor Endowments



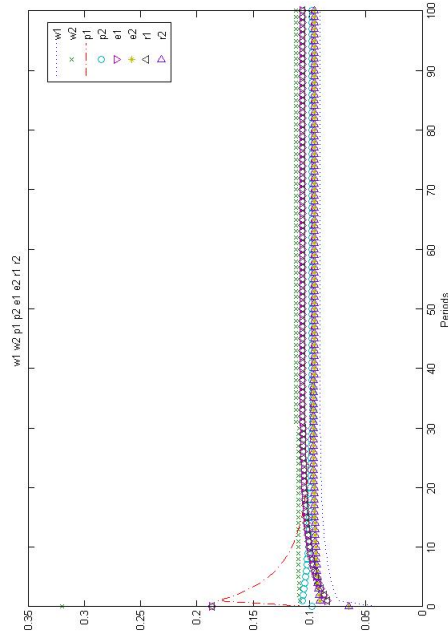
(b) Total Wealth



(c) Consumption Levels



(d) Factor Prices

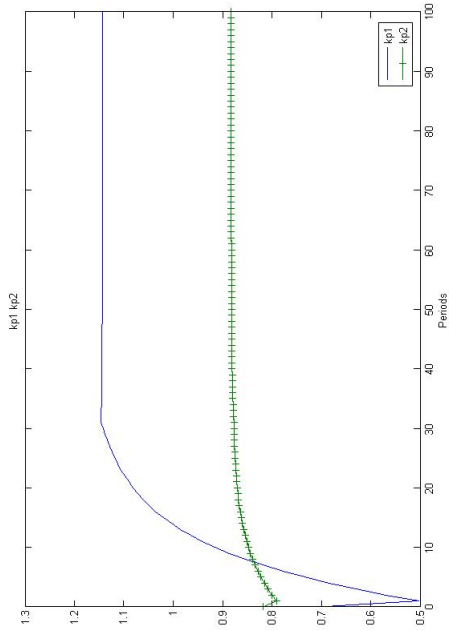


Simulations under the Structural Change (SC) hypothesis, scenarios in the Complete Specialisation (CS) equilibrium

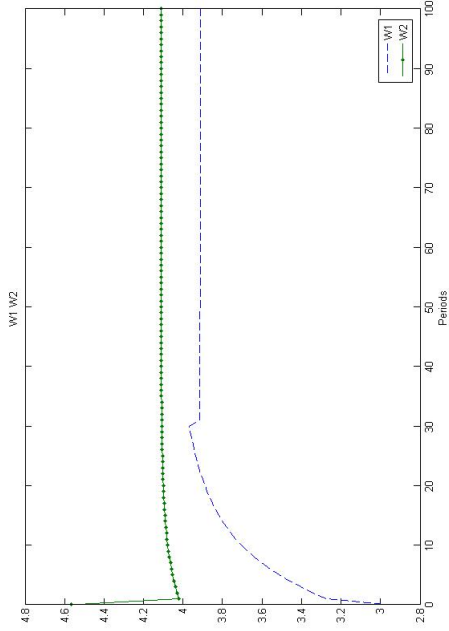
Source: Author's calculations

Scenario 3 under SC (temporary shock)

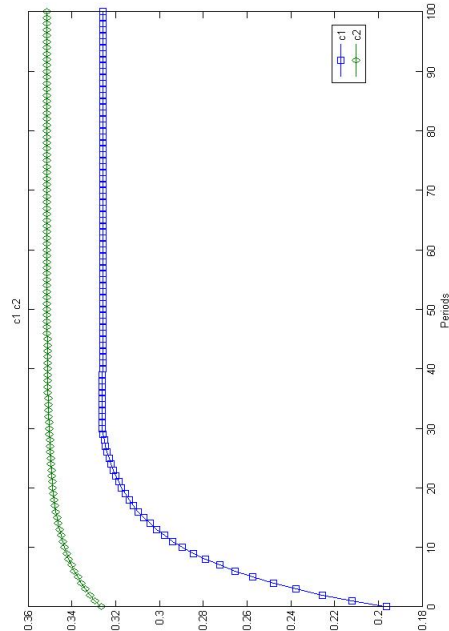
(a) Factor Endowments



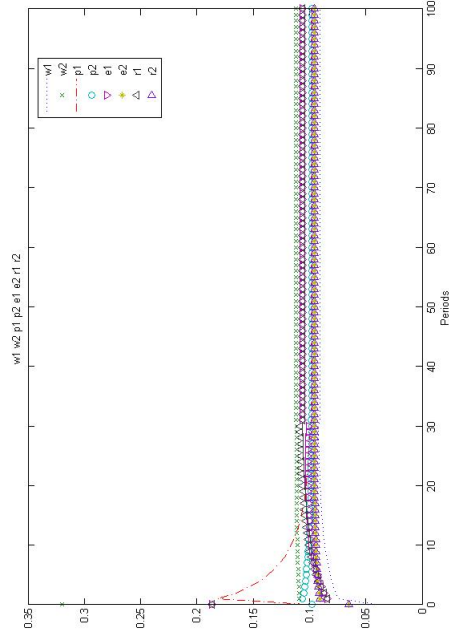
(b) Total Wealth



(c) Consumption Levels



(d) Factor Prices

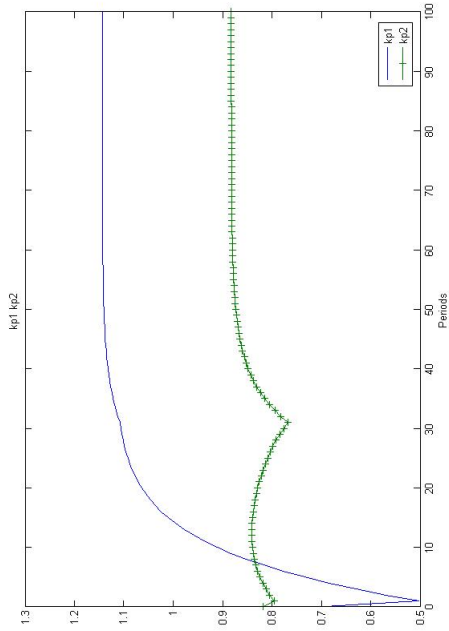


Simulations under the Structural Change (SC) hypothesis, scenarios in the Complete Specialisation (CS) equilibrium

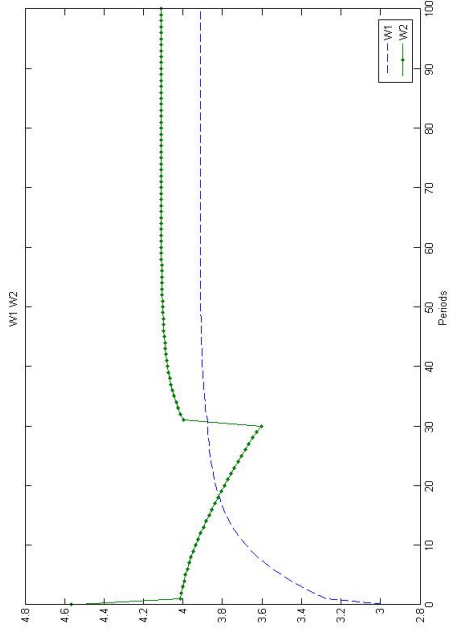
Source: Author's calculations

Scenario 4 under SC (temporary shock)

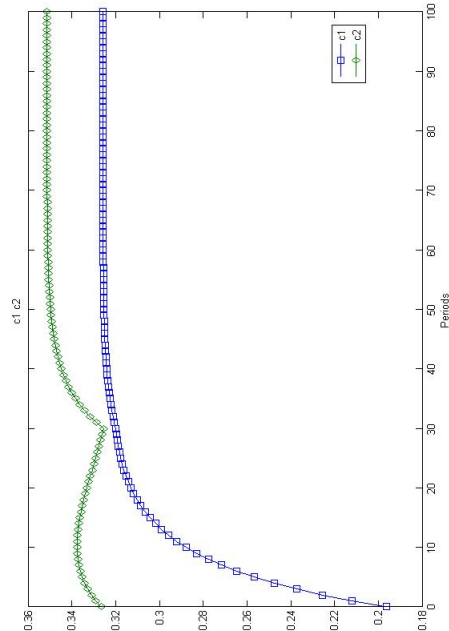
(a) Factor Endowments



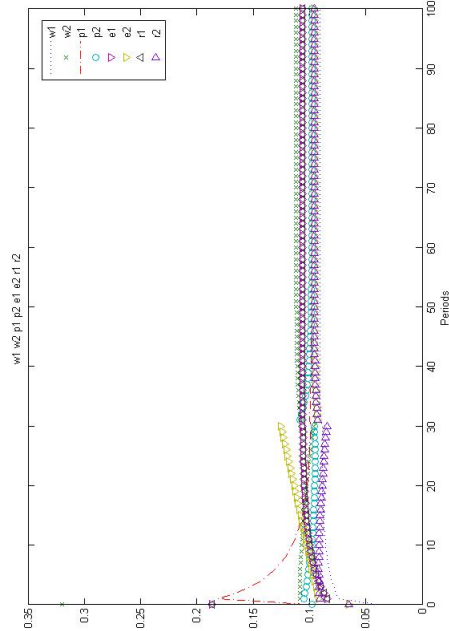
(b) Total Wealth



(c) Consumption Levels



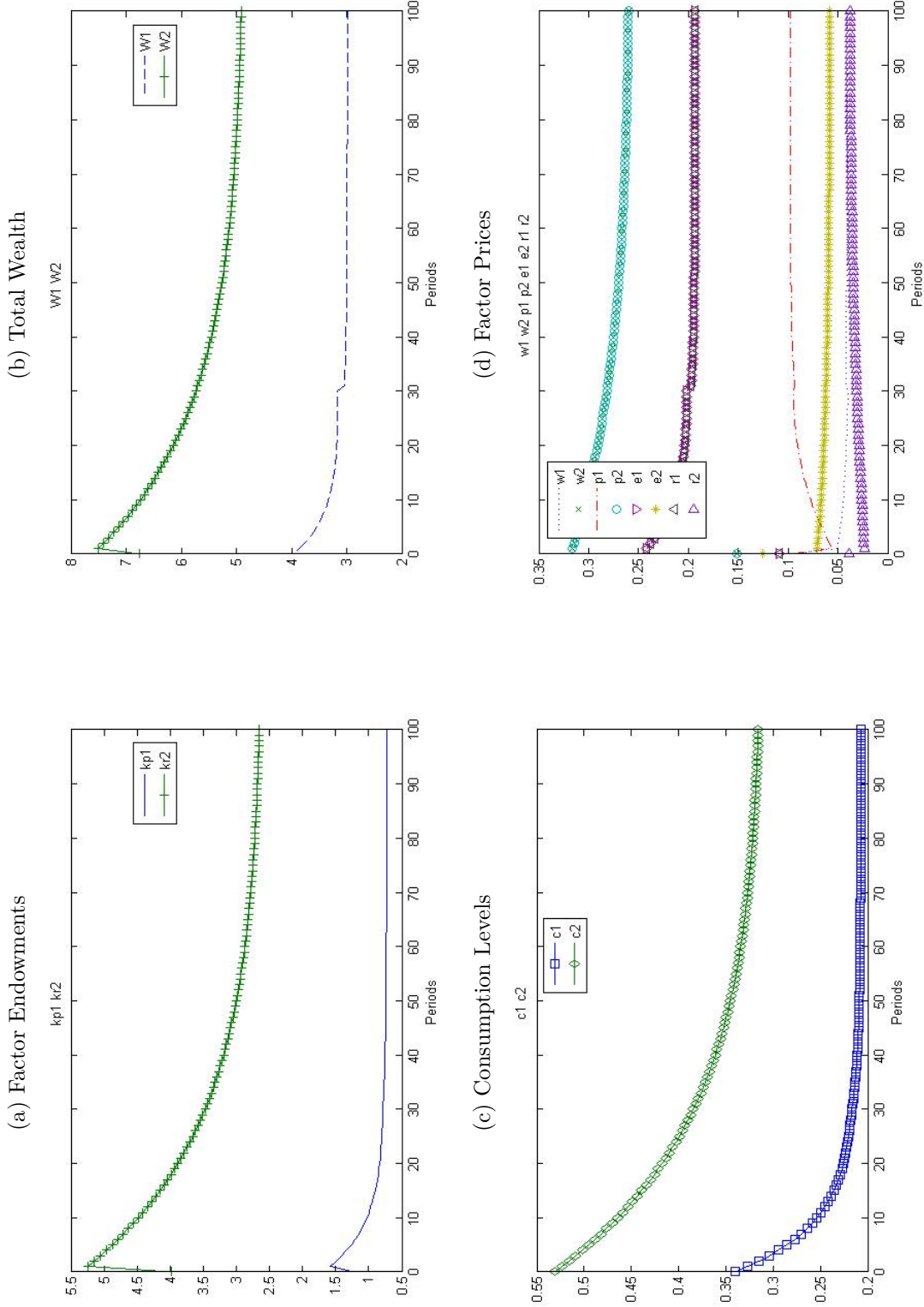
(d) Factor Prices



Simulations under the Structural Change (SC) hypothesis, scenarios in the Complete Specialisation (CS) equilibrium

Source: Author's calculations

Scenario 1 under CA (temporary shock)

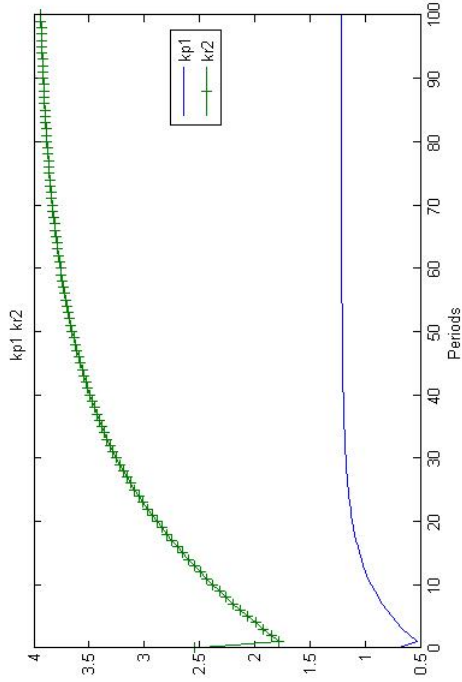


Simulations under the Comparative Advantage (CA) hypothesis, scenarios in the Complete Specialisation (CS) equilibrium

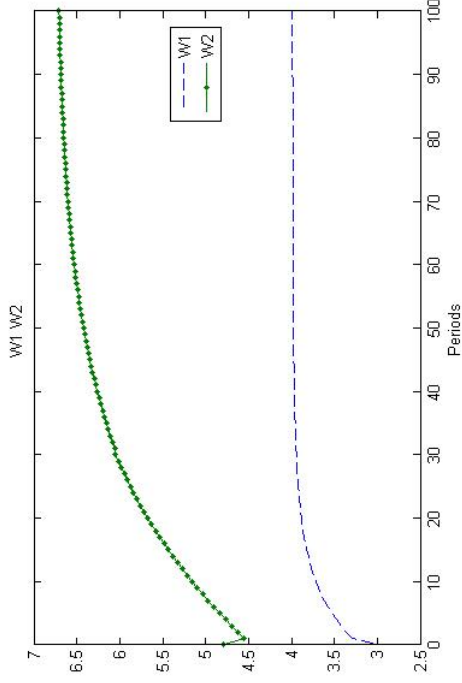
Source: Author's calculations

Scenario 2 under CA (temporary shock)

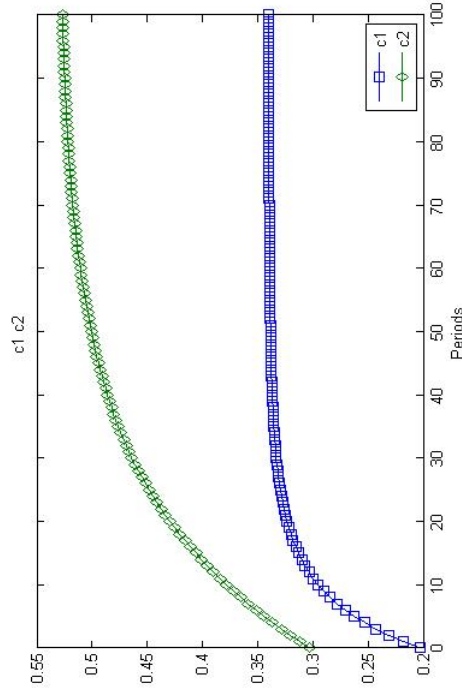
(a) Factor Endowments



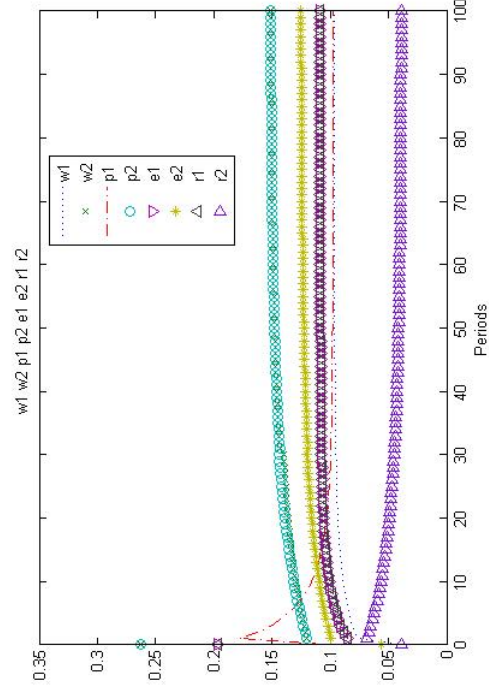
(b) Total Wealth



(c) Consumption Levels



(d) Factor Prices

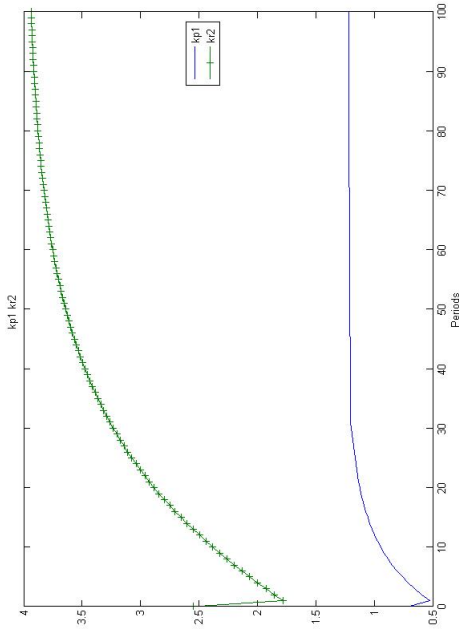


Simulations under the Comparative Advantage (CA) hypothesis, scenarios in the Complete Specialisation (CS) equilibrium

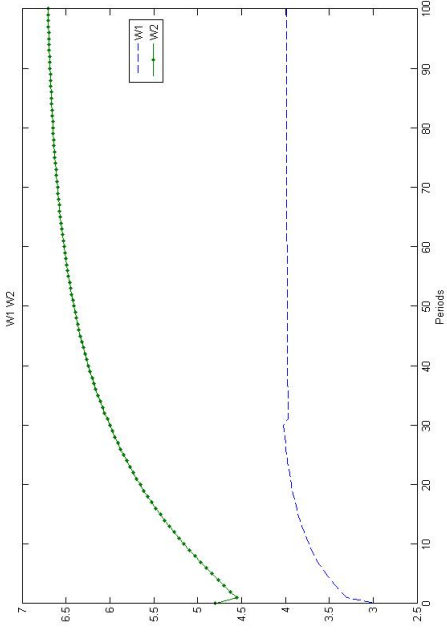
Source: Author's calculations

Scenario 3 under CA (temporary shock)

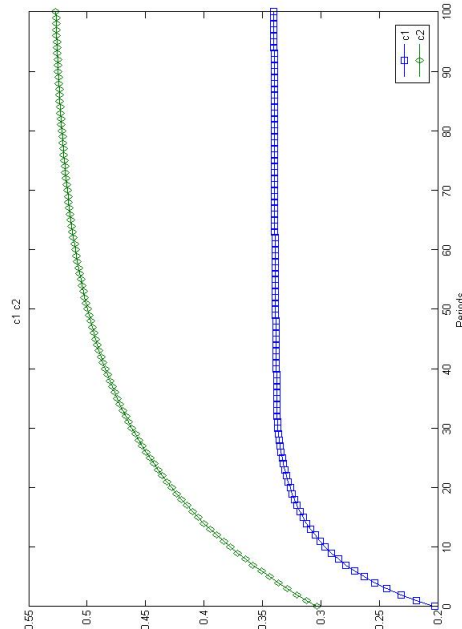
(a) Factor Endowments



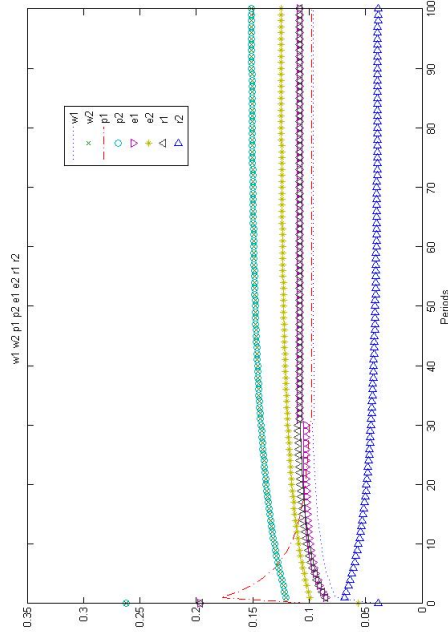
(b) Total Wealth



(c) Consumption Levels



(d) Factor Prices

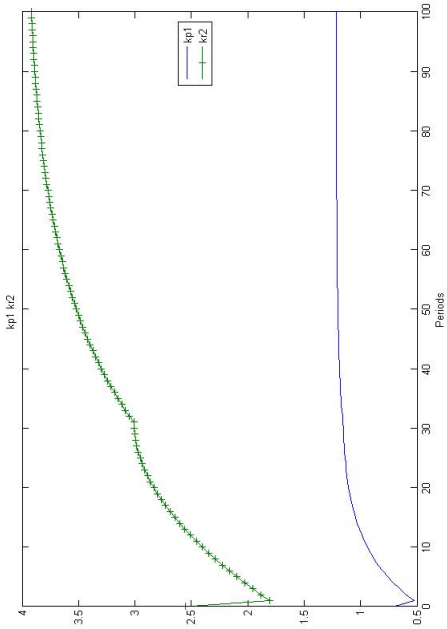


Simulations under the Comparative Advantage (CA) hypothesis, scenarios in the Complete Specialisation (CS) equilibrium

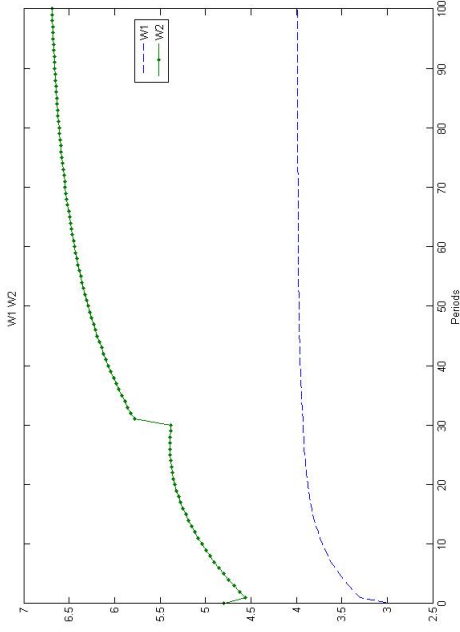
Source: Author's calculations

Scenario 4 under CA (temporary shock)

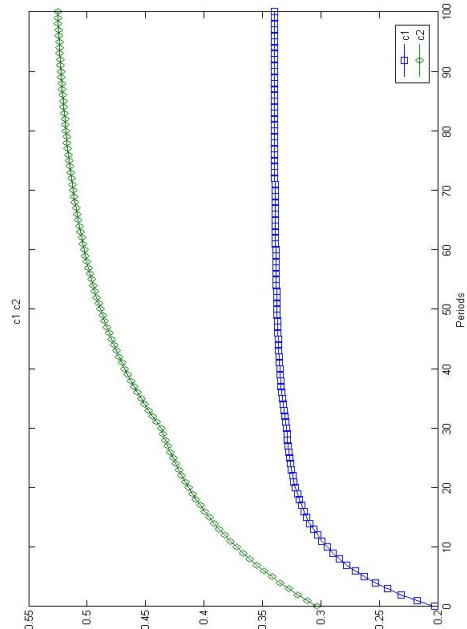
(a) Factor Endowments



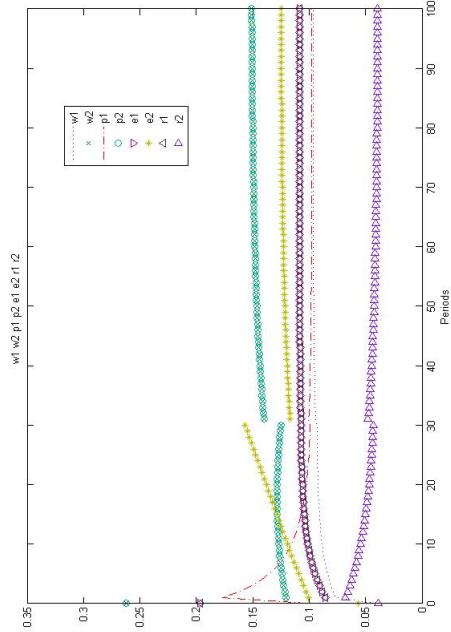
(b) Total Wealth



(c) Consumption Levels



(d) Factor Prices



Simulations under the Comparative Advantage (CA) hypothesis, scenarios in the Complete Specialisation (CS) equilibrium

Source: Author's calculations

APPENDIX F

Trade settings and scenarios in chapter 3

Variations under autarky between the CA (base) and SC cases (in %)

size	k=1,01	k=1,05	k=1,10	k=1,15	k=1,20	k=1,25	k=1,29	k=1,31	k=1,35	k=1,40	k=1,45	k=1,5	k=1,55	k=1,60	k=1,65	k=1,7	k=1,75
c	-22,89	-21,84	-20,47	-19,04	-17,52	-15,92	-14,55	-13,84	-12,34	-10,32	-8,091	-5,614	-2,817	0,398	4,1742	8,7413	14,464
W	-31,09	-30,15	-28,89	-27,55	-26,12	-24,58	-23,27	-22,58	-21,14	-19,2	-17,07	-14,73	-12,13	-9,213	-5,914	-2,118	2,309
Y	-15,02	-13,87	-12,37	-10,81	-9,171	-7,439	-5,975	-5,212	-3,62	-1,482	0,8513	3,4261	6,3045	9,5727	13,357	17,853	23,36
kp	29,251	32,244	36,104	40,13	44,337	48,769	52,505	54,445	58,49	63,9	69,782	76,25	83,452	91,599	101	112,11	125,67
kl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ke	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
kr	-72	-71,49	-70,77	-69,95	-69,01	-67,95	-66,99	-66,47	-65,34	-63,73	-61,84	-59,62	-56,95	-53,71	-49,67	-44,48	-37,55
c1	5E-05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
c2	-37,18	-35,49	-33,29	-30,98	-28,54	-25,94	-23,73	-22,58	-20,15	-16,87	-13,25	-9,214	-4,633	0,6563	6,9076	14,529	24,184
W1	-8E-06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W2	-47,36	-45,92	-44,02	-42,01	-39,85	-37,56	-35,59	-34,57	-32,41	-29,5	-26,3	-22,77	-18,82	-14,38	-9,284	-3,352	3,6891
Y1	-6E-05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Y2	-26,05	-24,05	-21,46	-18,76	-15,91	-12,9	-10,36	-9,041	-6,279	-2,571	1,4766	5,9427	10,936	16,604	23,169	30,967	40,521
kp1	-2E-05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
w1	0,0001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
p1	-2E-05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e1	4E-05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
r1	4E-05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
kr2	-70,69	-69,9	-68,87	-67,8	-66,66	-65,48	-64,47	-63,95	-62,85	-61,38	-59,78	-58,01	-56,03	-53,78	-51,18	-48,08	-44,3
w2	-26,05	-24,05	-21,46	-18,76	-15,91	-12,91	-10,36	-9,042	-6,279	-2,571	1,4766	5,9427	10,936	16,605	23,169	30,963	40,519
p2	-59,41	-60,48	-61,78	-63,06	-64,3	-65,54	-66,51	-67	-67,98	-69,19	-70,42	-71,67	-72,94	-74,26	-75,63	-77,08	-78,64
e2	-26,05	-24,05	-21,46	-18,76	-15,91	-12,91	-10,36	-9,042	-6,279	-2,571	1,4766	5,9427	10,936	16,605	23,169	30,963	40,519
r2	350,56	338,69	324,22	310,1	296,23	282,56	271,71	266,3	255,5	241,97	228,33	214,49	200,33	185,73	170,5	154,41	137,11

Variations under free trade between the CA (base) and SC cases (in %)

size	k=1,01	k=1,05	k=1,10	k=1,15	k=1,20	k=1,25	k=1,29	k=1,31	k=1,35	k=1,40	k=1,45	k=1,5	k=1,55	k=1,60	k=1,65	k=1,7	k=1,75
c	-37,12	-36	-34,28	-32,2	-30,05	-27,74	-25,85	-24,89	-22,92	-20,36	-17,69	-14,86	-11,84	-8,593	-5,053	-1,136	3,2866
W	-43,2	-41,66	-39,6	-37,37	-35,24	-32,87	-30,92	-29,92	-27,88	-25,24	-22,5	-19,64	-16,66	-13,53	-10,26	-6,8	-3,142
Y	-26,89	-25,79	-24,14	-22,18	-20,25	-18,14	-16,42	-15,55	-13,78	-11,5	-9,128	-6,646	-4,026	-1,236	1,7698	5,0511	8,6955
kp	-12,3	-9,766	-6,461	-3,002	-0,111	3,1718	5,7637	7,0513	9,6155	12,812	16,015	19,247	22,531	25,897	29,38	33,029	36,913
kl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ke	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
kr	-161,2	-157,6	-152,7	-147,3	-141,4	-135	-129,6	-126,7	-120,8	-112,9	-104,5	-95,45	-85,82	-75,52	-64,5	-52,67	-39,94
c1	-6,725	-5,903	-4,635	-3,1	-4,485	-4,419	-4,362	-4,333	-4,27	-4,186	-4,092	-3,986	-3,866	-3,726	-3,56	-3,358	-3,101
c2	-67,51	-66,09	-63,92	-61,3	-54,19	-49,09	-45,03	-43	-38,92	-33,78	-28,55	-23,22	-17,73	-12,04	-6,06	0,284	7,1256
W1	-6,678	-4,786	-2,382	0,0647	-1,959	-1,861	-1,776	-1,731	-1,637	-1,509	-1,37	-1,218	-1,051	-0,867	-0,665	-0,44	-0,191
W2	-79,83	-79,08	-77,91	-76,47	-67,55	-61,99	-57,55	-55,34	-50,91	-45,35	-39,78	-34,18	-28,52	-22,81	-17	-11,1	-5,052
Y1	-8,663	-7,102	-4,942	-2,553	-4,636	-4,543	-4,464	-4,423	-4,336	-4,218	-4,087	-3,941	-3,775	-3,583	-3,357	-3,084	-2,742
Y2	-45,16	-44,73	-43,86	-42,63	-35,36	-30,86	-27,31	-25,54	-22,02	-17,62	-13,2	-8,743	-4,212	0,4267	5,2174	10,215	15,492
kp1	-25,9	-17,6	-8,23	0,2108	-6,704	-6,373	-6,094	-5,95	-5,65	-5,249	-4,815	-4,339	-3,813	-3,221	-2,544	-1,752	-0,8
w1	-26,58	-20,65	-13,6	-6,896	-6,704	-6,373	-6,094	-5,95	-5,65	-5,249	-4,815	-4,339	-3,813	-3,221	-2,544	-1,752	-0,8
p1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e1	9,3117	6,3358	2,4596	-1,619	-1,827	-2,046	-2,23	-2,326	-2,524	-2,787	-3,071	-3,381	-3,721	-4,101	-4,532	-5,028	-5,615
r1	9,3117	6,3358	2,4596	-1,619	-1,827	-2,046	-2,23	-2,326	-2,524	-2,787	-3,071	-3,381	-3,721	-4,101	-4,532	-5,028	-5,615
kr2	-320,4	-345,1	-380,2	-421,2	-360,2	-345,7	-334,3	-328,7	-317,7	-304	-290,5	-277,1	-263,8	-250,6	-237,5	-224,4	-211,6
w2	-27,17	-31,24	-36,53	-42,08	-38,33	-33,42	-29,54	-27,61	-23,76	-18,96	-14,13	-9,243	-4,259	0,8728	6,2194	11,871	17,96
p2	-30,12	-34,29	-39,7	-45,37	-51,35	-57,68	-63,05	-65,84	-71,69	-79,53	-88,08	-97,5	-108	-119,8	-133,4	-149,3	-168,4
e2	-62,41	-55,04	-46,29	-37,97	-33,19	-29	-25,68	-24,04	-20,75	-16,64	-12,53	-8,382	-4,179	0,106	4,502	9,0436	13,769
r2	61,263	61,263	61,263	61,263	60,323	59,185	58,232	57,739	56,717	55,361	53,9	52,312	50,564	48,615	46,405	43,844	40,794

For values $k < 1.20$ the complete specialisation (CS) trade model reverts to integrated equilibrium (IE).

Variations in SC between autarky (base) and CS cases (in %)

size	k=1,01	k=1,05	k=1,10	k=1,15	k=1,20	k=1,25	k=1,29	k=1,31	k=1,35	k=1,40	k=1,45	k=1,5	k=1,55	k=1,60	k=1,65	k=1,7	k=1,75
c	-44,14	-44,08	-43,89	-43,56	-43,22	-42,83	-42,52	-42,35	-42,02	-41,6	-41,15	-40,68	-40,18	-39,65	-39,06	-38,4	-37,66
W	-16,14	-16,11	-16	-15,83	-15,73	-15,52	-15,33	-15,23	-15,02	-14,72	-14,4	-14,04	-13,65	-13,21	-12,72	-12,16	-11,53
Y	-43,08	-43,02	-42,83	-42,51	-42,2	-41,82	-41,51	-41,35	-41,02	-40,6	-40,16	-39,7	-39,2	-38,66	-38,07	-37,42	-36,67
kp	-43,08	-43,02	-42,83	-42,5	-42,46	-42,17	-41,93	-41,81	-41,57	-41,27	-40,96	-40,66	-40,35	-40,04	-39,73	-39,43	-39,16
kl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ke	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
kr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
c1	-43,97	-43,18	-42,05	-40,73	-41,06	-40,55	-40,13	-39,92	-39,48	-38,92	-38,31	-37,67	-36,98	-36,23	-35,39	-34,45	-33,35
c2	-44,32	-44,96	-45,62	-46,14	-45,13	-44,78	-44,49	-44,34	-44,04	-43,65	-43,24	-42,81	-42,35	-41,85	-41,3	-40,69	-39,99
W1	-15,74	-14,07	-11,85	-9,46	-11,02	-10,68	-10,38	-10,23	-9,902	-9,463	-8,987	-8,467	-7,898	-7,273	-6,583	-5,816	-4,959
W2	-16,54	-18,08	-19,89	-21,58	-19,85	-19,61	-19,4	-19,29	-19,05	-18,73	-18,37	-17,99	-17,56	-17,09	-16,57	-15,98	-15,32
Y1	-42,81	-41,66	-40,05	-38,22	-39,02	-38,53	-38,12	-37,91	-37,48	-36,91	-36,31	-35,67	-34,97	-34,2	-33,35	-32,38	-31,24
Y2	-43,35	-44,34	-45,43	-46,38	-44,97	-44,6	-44,28	-44,13	-43,8	-43,39	-42,95	-42,49	-42	-41,47	-40,89	-40,25	-39,51
kp1	-42,01	-37,58	-31,71	-25,41	-29,76	-29,04	-28,45	-28,14	-27,5	-26,66	-25,76	-24,8	-23,74	-22,57	-21,25	-19,73	-17,94
w1	-42,32	-39,16	-34,94	-30,38	-29,76	-29,05	-28,45	-28,14	-27,5	-26,66	-25,76	-24,8	-23,74	-22,56	-21,25	-19,73	-17,94
p1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e1	-43,46	-44,95	-46,77	-48,54	-48,27	-48,01	-47,79	-47,68	-47,45	-47,16	-46,86	-46,54	-46,2	-45,84	-45,46	-45,03	-44,54
r1	-43,46	-44,95	-46,77	-48,54	-48,27	-48,01	-47,79	-47,68	-47,45	-47,16	-46,86	-46,54	-46,2	-45,84	-45,46	-45,03	-44,54
kp2	-44,15	-48,29	-53,23	-57,96	-53,56	-53,23	-52,98	-52,85	-52,6	-52,28	-51,97	-51,65	-51,35	-51,04	-50,75	-50,49	-50,26
w2	-43,84	-46,76	-50,21	-53,47	-53,56	-53,23	-52,98	-52,85	-52,6	-52,28	-51,97	-51,65	-51,35	-51,04	-50,75	-50,49	-50,26
p2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e2	-42,7	-41,15	-39,15	-37,05	-36,39	-35,96	-35,59	-35,4	-35,01	-34,49	-33,93	-33,32	-32,65	-31,89	-31,02	-30	-28,77
r2	-42,7	-41,15	-39,15	-37,05	-36,39	-35,96	-35,59	-35,4	-35,01	-34,49	-33,93	-33,32	-32,65	-31,89	-31,02	-30	-28,77

For values $k < 1.20$ the complete specialisation (CS) trade model reverts to integrated equilibrium (IE).

APPENDIX G

Variance, covariance and correlation tables

Descriptive Statistics for sample g5

	gl1	rr	gl2	gl4	man	cp	vt	gg
1	Min. :0.0000	Min. : 0.1023	Min. :0.0000	Min. :0.00000	Min. : 1.857	Min. : 47.73	Min. : 14.77	Min. :-17.669
2	1st Qu.:0.1345	1st Qu.: 6.1740	1st Qu.:0.4011	1st Qu.:0.03476	1st Qu.: 7.865	1st Qu.: 58.26	1st Qu.: 47.47	1st Qu.: 2.643
3	Median :0.3273	Median :10.2655	Median :0.6221	Median :0.10872	Median :12.358	Median : 63.24	Median : 63.05	Median : 4.682
4	Mean :0.3949	Mean :16.9271	Mean :0.5951	Mean :0.24016	Mean :13.410	Mean : 87.96	Mean : 71.53	Mean : 4.496
5	3rd Qu.:0.6207	3rd Qu.:23.0578	3rd Qu.:0.8247	3rd Qu.:0.34509	3rd Qu.:17.690	3rd Qu.:120.77	3rd Qu.: 84.22	3rd Qu.: 6.881
6	Max. :0.9995	Max. :69.8595	Max. :0.9999	Max. :0.99754	Max. :33.971	Max. :192.20	Max. :562.06	Max. : 34.500

Variance table for sample g5

	gl1	rr	gl2	gl4	man	cp	vt	gg
gl1	0.08	-1.74	0.01	0.02	0.69	0.54	0.81	0.06
rr	-1.74	233.81	-0.41	-0.66	-39.52	137.19	183.20	9.31
gl2	0.01	-0.41	0.07	0.02	0.56	0.68	0.55	-0.08
gl4	0.02	-0.66	0.02	0.08	1.24	0.10	2.25	-0.05
man	0.69	-39.52	0.56	1.24	51.29	-39.20	-0.21	-0.19
cp	0.54	137.19	0.68	0.10	-39.20	1780.94	213.62	34.98
vt	0.81	183.20	0.55	2.25	-0.21	213.62	1662.49	3.98
gg	0.06	9.31	-0.08	-0.05	-0.19	34.98	3.98	21.52

Correlation table using the Pearson coefficients for sample g5

	gl1	rr	gl2	gl4	man	cp	vt	gg
gl1	1.00	-0.40	0.15	0.27	0.34	0.04	0.07	0.05
rr	-0.40	1.00	-0.10	-0.15	-0.36	0.21	0.29	0.13
gl2	0.15	-0.10	1.00	0.32	0.29	0.06	0.05	-0.06
gl4	0.27	-0.15	0.32	1.00	0.60	0.01	0.19	-0.04
man	0.34	-0.36	0.29	0.60	1.00	-0.13	-0.00	-0.01
cp	0.04	0.21	0.06	0.01	-0.13	1.00	0.12	0.18
vt	0.07	0.29	0.05	0.19	-0.00	0.12	1.00	0.02
gg	0.05	0.13	-0.06	-0.04	-0.01	0.18	0.02	1.00

Correlation table using the Spearman coefficients for sample g5

	gl1	rr	gl2	gl4	man	cp	vt	gg
gl1	1.00	-0.41	0.12	0.21	0.35	0.03	-0.05	0.10
rr	-0.41	1.00	-0.11	-0.08	-0.32	0.28	0.46	0.04
gl2	0.12	-0.11	1.00	0.34	0.25	0.05	0.00	-0.04
gl4	0.21	-0.08	0.34	1.00	0.49	0.03	0.15	0.02
man	0.35	-0.32	0.25	0.49	1.00	-0.13	-0.15	0.01
cp	0.03	0.28	0.05	0.03	-0.13	1.00	0.21	0.28
vt	-0.05	0.46	0.00	0.15	-0.15	0.21	1.00	0.07
gg	0.10	0.04	-0.04	0.02	0.01	0.28	0.07	1.00

Descriptive Statistics for sample g2

	gl1	rr	gl2	gl4	man	cp	vt	gg
1	Min. :0.0000	Min. : 0.1023	Min. :0.0000	Min. :0.00000	Min. : 0.000	Min. : 47.73	Min. : 14.77	Min. :-17.669
2	1st Qu.:0.1962	1st Qu.: 2.9577	1st Qu.:0.4022	1st Qu.:0.04602	1st Qu.: 8.975	1st Qu.: 58.30	1st Qu.: 46.29	1st Qu.: 2.456
3	Median :0.4261	Median : 5.9189	Median :0.6536	Median :0.13887	Median :14.182	Median : 63.24	Median : 66.82	Median : 4.548
4	Mean :0.4511	Mean :11.4737	Mean :0.6082	Mean :0.27121	Mean :14.425	Mean : 89.77	Mean : 74.54	Mean : 4.365
5	3rd Qu.:0.6888	3rd Qu.:12.7114	3rd Qu.:0.8539	3rd Qu.:0.43396	3rd Qu.:18.072	3rd Qu.:120.80	3rd Qu.: 94.11	3rd Qu.: 6.562
6	Max. :0.9999	Max. :69.8595	Max. :0.9999	Max. :0.99918	Max. :41.724	Max. :192.20	Max. :562.06	Max. : 34.500

Variance table for sample g2

	gl1	rr	gl2	gl4	man	cp	vt	gg
gl1	0.08	-1.50	0.01	0.02	0.68	0.17	1.62	-0.01
rr	-1.50	185.89	-0.32	-0.61	-32.47	78.01	81.94	6.80
gl2	0.01	-0.32	0.08	0.03	0.58	0.56	1.31	-0.15
gl4	0.02	-0.61	0.03	0.09	1.24	-0.02	2.50	-0.07
man	0.68	-32.47	0.58	1.24	51.88	-32.38	62.07	-0.43
cp	0.17	78.01	0.56	-0.02	-32.38	1845.37	251.58	23.30
vt	1.62	81.94	1.31	2.50	62.07	251.58	1647.30	-1.51
gg	-0.01	6.80	-0.15	-0.07	-0.43	23.30	-1.51	18.47

Correlation table using the Pearson coefficients for sample g2

	gl1	rr	gl2	gl4	man	cp	vt	gg
gl1	1.00	-0.39	0.14	0.30	0.34	0.01	0.14	-0.00
rr	-0.39	1.00	-0.08	-0.15	-0.33	0.13	0.15	0.12
gl2	0.14	-0.08	1.00	0.40	0.28	0.05	0.11	-0.13
gl4	0.30	-0.15	0.40	1.00	0.59	-0.00	0.21	-0.05
man	0.34	-0.33	0.28	0.59	1.00	-0.10	0.21	-0.01
cp	0.01	0.13	0.05	-0.00	-0.10	1.00	0.14	0.13
vt	0.14	0.15	0.11	0.21	0.21	0.14	1.00	-0.01
gg	-0.00	0.12	-0.13	-0.05	-0.01	0.13	-0.01	1.00

Correlation table using the Spearman coefficients for sample g2

	gl1	rr	gl2	gl4	man	cp	vt	gg
gl1	1.00	-0.37	0.11	0.27	0.37	0.01	0.11	0.03
rr	-0.37	1.00	-0.07	-0.12	-0.29	0.16	0.08	0.07
gl2	0.11	-0.07	1.00	0.40	0.26	0.04	0.11	-0.11
gl4	0.27	-0.12	0.40	1.00	0.52	0.02	0.16	-0.01
man	0.37	-0.29	0.26	0.52	1.00	-0.12	0.11	0.01
cp	0.01	0.16	0.04	0.02	-0.12	1.00	0.20	0.20
vt	0.11	0.08	0.11	0.16	0.11	0.20	1.00	0.00
gg	0.03	0.07	-0.11	-0.01	0.01	0.20	0.00	1.00

APPENDIX H

Fixed effects across specifications

Regressions for the g5 sample

Fixed-effects for regression 2 model 1

Country	Estimate	Std. Error	t-value	Pr(> t)	Country	Estimate	Std. Error	t-value	Pr(> t)
ARE	16.591327	3.957123	4.1928	2.756e-05 ***	MOZ	3.763620	2.873596	1.3097	0.1902890
ARG	7.813879	3.062701	2.5513	0.0107321 *	MRT	18.846816	2.392023	7.8790	3.331e-15 ***
AZE	36.830396	2.158767	17.0609	< 2.2e-16 ***	MWI	1.635525	2.320413	0.7048	0.4809084
BDI	9.759799	2.103997	4.6387	3.506e-06 ***	MYS	6.446597	4.509115	1.4297	0.1528086
BOL	14.047561	2.539638	5.5313	3.178e-08 ***	NGA	25.061593	1.894434	13.2291	< 2.2e-16 ***
BRN	38.692370	2.757553	14.0314	< 2.2e-16 ***	NOR	7.837446	2.495624	3.1405	0.0016867 **
BTN	7.115129	2.742246	2.5946	0.0094691 **	OMN	27.770357	2.123229	13.0793	< 2.2e-16 ***
CAF	0.587337	1.853623	0.3169	0.7513505	PER	6.677352	2.699203	2.4738	0.0133676 *
CHL	10.420056	2.661507	3.9151	9.037e-05 ***	PNG	27.741320	2.912920	9.5235	< 2.2e-16 ***
CHN	9.853844	4.471819	2.2035	0.0275565 *	ROM	9.450174	3.777967	2.5014	0.0123706 *
CMR	11.799245	3.014130	3.9146	9.054e-05 ***	RUS	24.096105	3.079573	7.8245	5.107e-15 ***
COG	46.324244	2.810846	16.4805	< 2.2e-16 ***	SAU	38.302939	2.077393	18.4380	< 2.2e-16 ***
COL	6.447271	2.477324	2.6025	0.0092543 **	SDN	8.932874	2.026237	4.4086	1.040e-05 ***
DZA	17.855627	2.491602	7.1663	7.703e-13 ***	SLB	4.720378	4.421195	1.0677	0.2856693
ECU	16.735601	2.585970	6.4717	9.691e-11 ***	SLE	-2.990737	4.317923	-0.6926	0.4885397
EGY	12.833817	2.792407	4.5960	4.307e-06 ***	SUR	6.847980	2.672077	2.5628	0.0103834 *
ETH	3.110153	1.978299	1.5721	0.1159193	SYR	18.789766	4.355388	4.3141	1.602e-05 ***
GAB	36.499917	1.997522	18.2726	< 2.2e-16 ***	TKM	54.955513	6.480062	8.4807	< 2.2e-16 ***
GHA	0.476066	2.420192	0.1967	0.8440577	TTO	25.954482	2.396766	10.8290	< 2.2e-16 ***
GIN	5.123291	1.921210	2.6667	0.0076600 **	TZA	-0.040024	2.066584	-0.0194	0.9845483
GUY	-3.623246	3.167212	-1.1440	0.2526295	UGA	1.377320	1.941678	0.7093	0.4781102
IDN	13.383331	3.747744	3.5710	0.0003556 ***	UKR	5.258285	3.746806	1.4034	0.1604962
IRN	32.445945	2.488567	13.0380	< 2.2e-16 ***	VEN	28.816312	2.641776	10.9079	< 2.2e-16 ***
KAZ	35.556449	2.727403	13.0367	< 2.2e-16 ***	VNM	6.385709	3.324396	1.9209	0.0547490 .
KWT	36.994590	3.125522	11.8363	< 2.2e-16 ***	YEM	23.439474	2.705728	8.6629	< 2.2e-16 ***
LBY	46.457218	4.405885	10.5444	< 2.2e-16 ***	ZAF	5.708961	3.034969	1.8811	0.0599637 .
MEX	4.499458	3.268010	1.3768	0.1685682	ZMB	8.710569	2.476555	3.5172	0.0004361 ***
MLI	-3.217217	1.977284	-1.6271	0.1037181	ZWE	5.750663	3.002803	1.9151	0.0554799 .
MNG	6.290972	2.330832	2.6990	0.0069543 **					

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, $p < 0.1$

Fixed-effects for regression 1 model 1

Country	Estimate	Std. Error	t-value	Pr(> t)	Country	Estimate	Std. Error	t-value	Pr(> t)
ARE	0.193544	0.097390	1.9873	0.0468870 *	MNG	0.038215	0.058323	0.6552	0.5123179
ARG	0.032531	0.047962	0.6783	0.4976006	MOZ	0.541713	0.052826	10.2547	< 2.2e-16 ***
AZE	0.268563	0.056690	4.7374	2.165e-06 ***	MRT	0.236719	0.054584	4.3368	1.446e-05 ***
BDI	0.249289	0.041216	6.0484	1.463e-09 ***	MWI	0.247597	0.042181	5.8698	4.363e-09 ***
BHR	0.127383	0.068682	1.8547	0.0636407 .	MYS	0.498145	0.079982	6.2282	4.717e-10 ***

BOL	0.156085	0.048091	3.2456	0.0011720 **	NGA	0.133751	0.050777	2.6341	0.0084365 **
BRN	0.176693	0.062545	2.8251	0.0047272 **	NOR	-0.108134	0.058940	-1.8346	0.0665577 .
BTN	0.809633	0.056764	14.2631	< 2.2e-16 ***	OMN	0.089073	0.051465	1.7307	0.0834971 .
CAF	0.166889	0.041777	3.9948	6.476e-05 ***	PER	0.608853	0.042112	14.4581	< 2.2e-16 ***
CHL	0.474925	0.041907	11.3328	< 2.2e-16 ***	PNG	0.076288	0.075307	1.0130	0.3110494
CHN	0.282163	0.057374	4.9180	8.744e-07 ***	QAT	0.083975	0.060147	1.3962	0.1626650
CMR	0.349766	0.045500	7.6872	1.510e-14 ***	ROM	0.197652	0.055700	3.5485	0.0003874 ***
COG	0.049485	0.079072	0.6258	0.5314302	RUS	0.172665	0.053709	3.2148	0.0013054 **
COL	0.153916	0.041902	3.6732	0.0002395 ***	SAU	0.076976	0.054278	1.4182	0.1561369
DZA	0.349069	0.041660	8.3791	< 2.2e-16 ***	SDN	0.530096	0.040230	13.1765	< 2.2e-16 ***
ECU	0.086926	0.040122	2.1665	0.0302718 *	SLB	0.421203	0.082226	5.1225	3.015e-07 ***
EGY	0.523487	0.041680	12.5598	< 2.2e-16 ***	SLE	0.196156	0.109927	1.7844	0.0743545 .
ETH	0.537429	0.041449	12.9661	< 2.2e-16 ***	SUR	0.611887	0.052172	11.7284	< 2.2e-16 ***
GAB	0.062083	0.057101	1.0873	0.2769227	SYR	0.271084	0.055380	4.8950	9.830e-07 ***
GHA	0.593643	0.050922	11.6579	< 2.2e-16 ***	TKM	0.255116	0.163935	1.5562	0.1196598
GIN	-0.014804	0.051168	-0.2893	0.7723318	TTO	0.709586	0.054936	12.9167	< 2.2e-16 ***
GNB	0.104130	0.089987	1.1572	0.2472072	TZA	0.250258	0.045520	5.4978	3.846e-08 ***
GUY	0.149163	0.078090	1.9101	0.0561166 .	UGA	0.259411	0.040416	6.4185	1.376e-10 ***
IDN	0.357215	0.055025	6.4919	8.479e-11 ***	UKR	0.582833	0.061903	9.4152	< 2.2e-16 ***
IRN	0.144835	0.056382	2.5688	0.0102050 *	VEN	0.034317	0.048400	0.7090	0.4782994
KAZ	0.099956	0.060707	1.6465	0.0996534 .	VNM	0.203154	0.061008	3.3300	0.0008685 ***
KWT	0.116456	0.068112	1.7098	0.0873070 .	YEM	0.381662	0.064836	5.8866	3.943e-09 ***
LBY	0.053693	0.121411	0.4422	0.6583131	ZAF	0.554932	0.049123	11.2968	< 2.2e-16 ***
MEX	0.261930	0.059963	4.3682	1.253e-05 ***	ZMB	0.659419	0.045017	14.6481	< 2.2e-16 ***
MLI	0.134178	0.048376	2.7737	0.0055430 **	ZWE	0.298029	0.055565	5.3636	8.158e-08 ***

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$; $p < 0.1$

Fixed-effects for regression 2 model 2

Country	Estimate	Std. Error	t-value	Pr(> t)	Country	Estimate	Std. Error	t-value	Pr(> t)
ARE	26.2651	3.5494	7.3999	1.363e-13 ***	MOZ	12.8898	2.5116	5.1322	2.864e-07 ***
ARG	13.8308	2.7214	5.0822	3.730e-07 ***	MRT	26.8608	2.0948	12.8226	< 2.2e-16 ***
AZE	45.5867	1.9591	23.2696	< 2.2e-16 ***	MWI	8.4365	2.0010	4.2161	2.485e-05 ***
BDI	15.7842	1.7755	8.8898	< 2.2e-16 ***	MYS	17.0295	4.1238	4.1296	3.634e-05 ***
BOL	21.0181	2.1990	9.5579	< 2.2e-16 ***	NGA	32.4267	1.6943	19.1390	< 2.2e-16 ***
BRN	44.1663	2.4768	17.8319	< 2.2e-16 ***	NOR	15.4763	2.2523	6.8713	6.363e-12 ***
BTN	16.0562	2.4498	6.5541	5.598e-11 ***	OMN	33.4526	1.9597	17.0704	< 2.2e-16 ***
CAF	7.4027	1.5948	4.6417	3.456e-06 ***	PER	13.8218	2.3475	5.8879	3.911e-09 ***
CHL	17.7105	2.3252	7.6167	2.598e-14 ***	PNG	32.9206	2.6625	12.3645	< 2.2e-16 ***
CHN	19.3883	4.0291	4.8120	1.494e-06 ***	ROM	15.6834	3.4093	4.6002	4.221e-06 ***
CMR	17.7701	2.6674	6.6620	2.701e-11 ***	RUS	33.6163	2.6557	12.6581	< 2.2e-16 ***
COG	54.7867	2.5701	21.3173	< 2.2e-16 ***	SAU	44.9720	1.7976	25.0171	< 2.2e-16 ***
COL	13.1103	2.1251	6.1693	6.861e-10 ***	SDN	16.0030	1.7463	9.1642	< 2.2e-16 ***
DZA	22.2814	2.2357	9.9662	< 2.2e-16 ***	SLB	14.6319	3.9921	3.6652	0.0002471 ***
ECU	23.2178	2.2282	10.4199	< 2.2e-16 ***	SLE	3.7307	3.9731	0.9390	0.3477449
EGY	19.9945	2.4267	8.2392	2.220e-16 ***	SUR	12.3404	2.3939	5.1550	2.536e-07 ***
ETH	10.5021	1.7337	6.0578	1.380e-09 ***	SYR	23.7807	3.9759	5.9812	2.215e-09 ***
GAB	42.0330	1.8143	23.1678	< 2.2e-16 ***	TKM	62.0204	5.9494	10.4246	< 2.2e-16 ***
GHA	8.3746	2.1454	3.9035	9.483e-05 ***	TTO	33.3669	2.1922	15.2205	< 2.2e-16 ***
GIN	11.0741	1.6988	6.5188	7.088e-11 ***	TZA	7.1630	1.7829	4.0177	5.877e-05 ***
GUY	2.3533	2.9237	0.8049	0.4208616	UGA	8.5841	1.6760	5.1219	3.025e-07 ***
IDN	21.9423	3.3316	6.5861	4.516e-11 ***	UKR	14.7439	3.3592	4.3892	1.138e-05 ***
IRN	37.9710	2.2019	17.2449	< 2.2e-16 ***	VEN	35.1090	2.2837	15.3735	< 2.2e-16 ***
KAZ	44.4281	2.3781	18.6822	< 2.2e-16 ***	VNM	16.2220	2.9549	5.4898	4.024e-08 ***
KWT	42.2970	2.8729	14.7228	< 2.2e-16 ***	YEM	32.2412	2.3597	13.6633	< 2.2e-16 ***
LBY	56.7981	3.9687	14.3116	< 2.2e-16 ***	ZAF	13.6295	2.6767	5.0919	3.545e-07 ***
MEX	13.2032	2.9313	4.5043	6.660e-06 ***	ZMB	15.8824	2.1840	7.2722	3.535e-13 ***
MLI	2.9175	1.7934	1.6268	0.1037867	ZWE	12.7886	2.6036	4.9118	9.023e-07 ***
MNG	12.6032	2.1143	5.9610	2.507e-09 ***					

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$; $p < 0.1$

Time fixed-effects for regression 2 model 2

Year	Estimate	Std. Error	t-value	Pr(> t)	Year	Estimate	Std. Error	t-value	Pr(> t)
1992	20.4044	2.5499	8.0019	1.332e-15 ***	2002	17.8768	1.8234	9.8043	< 2.2e-16 ***

1993	21.6581	2.2127	9.7880	< 2.2e-16 ***	2003	20.8878	1.9468	10.7294	< 2.2e-16 ***
1994	19.7998	2.1045	9.4083	< 2.2e-16 ***	2004	22.4365	1.9819	11.3204	< 2.2e-16 ***
1995	16.4061	2.0423	8.0331	8.882e-16 ***	2005	24.3686	1.9184	12.7027	< 2.2e-16 ***
1996	18.0516	1.9671	9.1765	< 2.2e-16 ***	2006	26.7837	1.9135	13.9971	< 2.2e-16 ***
1997	16.6673	1.9659	8.4781	< 2.2e-16 ***	2007	25.6239	1.8438	13.8971	< 2.2e-16 ***
1998	14.2370	1.9219	7.4078	1.286e-13 ***	2008	27.9495	1.8477	15.1265	< 2.2e-16 ***
1999	15.8403	1.9030	8.3237	< 2.2e-16 ***	2009	19.2371	1.8855	10.2027	< 2.2e-16 ***
2000	20.6451	1.8063	11.4293	< 2.2e-16 ***	2010	21.2185	1.8690	11.3526	< 2.2e-16 ***
2001	19.0227	1.8493	10.2865	< 2.2e-16 ***	2011	20.6185	1.9195	10.7418	< 2.2e-16 ***

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, $p < 0.1$

Fixed-effects for regression 1 model 2

Country	Estimate	Std. Error	t-value	Pr(> t)	Country	Estimate	Std. Error	t-value	Pr(> t)
ARE	0.2321837	0.1002891	2.3151	0.0206051 *	MNG	0.0638677	0.0604663	1.0563	0.2908527
ARG	0.0444220	0.0494352	0.8986	0.3688703	MOZ	0.5574000	0.0541025	10.3027	< 2.2e-16 ***
AZE	0.3256736	0.0657408	4.9539	7.274e-07 ***	MRT	0.2725558	0.0583833	4.6684	3.036e-06 ***
BDI	0.2657202	0.0424197	6.2641	3.750e-10 ***	MWI	0.2584486	0.0429479	6.0177	1.769e-09 ***
BHR	0.1719775	0.0736202	2.3360	0.0194908 *	MYS	0.5261879	0.0847790	6.2066	5.415e-10 ***
BOL	0.1803195	0.0504344	3.5753	0.0003498 ***	NGA	0.1748032	0.0562907	3.1054	0.0019004 **
BRN	0.2281078	0.0695514	3.2797	0.0010392 **	NOR	-0.0841212	0.0623755	-1.3486	0.1774575
BTN	0.8327996	0.0585044	14.2348	< 2.2e-16 ***	OMN	0.1390398	0.0593992	2.3408	0.0192442 *
CAF	0.1777709	0.0426985	4.1634	3.135e-05 ***	PER	0.6202088	0.0428317	14.4801	< 2.2e-16 ***
CHL	0.4930838	0.0435469	11.3230	< 2.2e-16 ***	PNG	0.1225886	0.0804525	1.5237	0.1275738
CHN	0.2953905	0.0598865	4.9325	8.118e-07 ***	QAT	0.1361340	0.0669307	2.0340	0.0419561 *
CMR	0.3661743	0.0467405	7.8342	4.663e-15 ***	ROM	0.2105895	0.0579382	3.6347	0.0002783 ***
COG	0.1203616	0.0899039	1.3388	0.1806417	RUS	0.2072333	0.0587735	3.5260	0.0004219 ***
COL	0.1662888	0.0428374	3.8819	0.0001037 ***	SAU	0.1310098	0.0622917	2.1032	0.0354512 *
DZA	0.3806799	0.0454544	8.3750	< 2.2e-16 ***	SDN	0.5466201	0.0414382	13.1912	< 2.2e-16 ***
ECU	0.1101877	0.0424744	2.5942	0.0094807 **	SLB	0.4451393	0.0836829	5.3194	1.041e-07 ***
EGY	0.5415073	0.0430887	12.5673	< 2.2e-16 ***	SLE	0.2051225	0.1105685	1.8552	0.0635731 .
ETH	0.5503873	0.0422591	13.0241	< 2.2e-16 ***	SUR	0.6242770	0.0529535	11.7892	< 2.2e-16 ***
GAB	0.1179961	0.0655683	1.7996	0.0719250 .	SYR	0.3024300	0.0585883	5.1620	2.444e-07 ***
GHA	0.6084217	0.0519705	11.7071	< 2.2e-16 ***	TKM	0.3302091	0.1699971	1.9424	0.0520838 .
GIN	0.0044222	0.0525347	0.0842	0.9329163	TTO	0.7550823	0.0611254	12.3530	< 2.2e-16 ***
GNB	0.1122985	0.0905938	1.2396	0.2151300	TZA	0.2616157	0.0462400	5.6578	1.533e-08 ***
GUY	0.1722309	0.0802168	2.1471	0.0317879 *	UGA	0.2706644	0.0411548	6.5767	4.809e-11 ***
IDN	0.3766159	0.0577918	6.5168	7.184e-11 ***	UKR	0.5988935	0.0648929	9.2289	< 2.2e-16 ***
IRN	0.1850853	0.0610441	3.0320	0.0024295 **	VEN	0.0716348	0.0530394	1.3506	0.1768244
KAZ	0.1533420	0.0680552	2.2532	0.0242465 *	VNM	0.2271036	0.0639263	3.5526	0.0003815 ***
KWT	0.1780485	0.0764907	2.3277	0.0199273 *	YEM	0.4197424	0.0685375	6.1243	9.110e-10 ***
LBY	0.1260871	0.1283618	0.9823	0.3259623	ZAF	0.5670305	0.0508197	11.1577	< 2.2e-16 ***
MEX	0.2745122	0.0628641	4.3668	1.261e-05 ***	ZMB	0.6789982	0.0467154	14.5348	< 2.2e-16 ***
MLI	0.1475700	0.0493436	2.9907	0.0027837 **	ZWE	0.3140450	0.0569026	5.5190	3.410e-08 ***

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, $p < 0.1$

Time fixed-effects for regression 1 model 2

Year	Estimate	Std. Error	t-value	Pr(> t)	Year	Estimate	Std. Error	t-value	Pr(> t)
1992	0.302644	0.049390	6.1276	8.919e-10 ***	2002	0.270504	0.038222	7.0772	1.471e-12 ***
1993	0.276534	0.045958	6.0171	1.775e-09 ***	2003	0.318038	0.040100	7.9311	2.220e-15 ***
1994	0.325339	0.041506	7.8383	4.663e-15 ***	2004	0.312365	0.041330	7.5579	4.086e-14 ***
1995	0.292648	0.039939	7.3274	2.347e-13 ***	2005	0.347222	0.042551	8.1601	4.441e-16 ***
1996	0.295106	0.039043	7.5584	4.086e-14 ***	2006	0.314501	0.044579	7.0549	1.727e-12 ***
1997	0.301121	0.038347	7.8526	3.997e-15 ***	2007	0.310288	0.043682	7.1034	1.217e-12 ***
1998	0.311715	0.037562	8.2986	< 2.2e-16 ***	2008	0.331374	0.045552	7.2747	3.473e-13 ***
1999	0.283928	0.038795	7.3186	2.505e-13 ***	2009	0.324983	0.041457	7.8391	4.441e-15 ***
2000	0.285368	0.040123	7.1123	1.141e-12 ***	2010	0.349644	0.041336	8.4586	< 2.2e-16 ***
2001	0.277597	0.039602	7.0096	2.389e-12 ***	2011	0.316483	0.042396	7.4649	8.327e-14 ***

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, $p < 0.1$

Fixed-effects for regression 2 model 3

Country	Estimate	Std. Error	t-value	Pr(> t)	Country	Estimate	Std. Error	t-value	Pr(> t)
ARE	10.7805	2.5631	4.2061	2.599e-05 ***	MOZ	5.6335	1.8058	3.1197	0.0018103 **
ARG	5.9435	1.9791	3.0031	0.0026723 **	MRT	11.8300	1.5886	7.4469	9.548e-14 ***
AZE	13.3702	1.8495	7.2292	4.858e-13 ***	MWI	4.0584	1.4325	2.8331	0.0046095 **
BDI	5.7506	1.3169	4.3667	1.261e-05 ***	MYS	8.0104	3.0230	2.6498	0.0080543 **
BOL	8.0998	1.6590	4.8823	1.049e-06 ***	NGA	8.6542	1.4939	5.7932	6.905e-09 ***
BRN	13.0783	2.1816	5.9947	2.038e-09 ***	NOR	5.0986	1.6670	3.0585	0.0022246 **
BTN	5.8549	1.7724	3.3033	0.0009554 ***	OMN	10.6092	1.6767	6.3275	2.492e-10 ***
CAF	2.8385	1.1418	2.4860	0.0129180 *	PER	6.2233	1.6994	3.6621	0.0002502 ***
CHL	7.2867	1.7057	4.2720	1.937e-05 ***	PNG	11.9045	2.0422	5.8292	5.570e-09 ***
CHN	7.6380	2.9556	2.5842	0.0097597 **	ROM	6.4619	2.4716	2.6145	0.0089362 **
CMR	7.2811	1.9448	3.7439	0.0001812 ***	RUS	9.6482	2.1099	4.5729	4.811e-06 ***
COG	15.6530	2.3447	6.6759	2.456e-11 ***	SAU	14.4743	1.7459	8.2907	2.220e-16 ***
COL	5.3885	1.5465	3.4843	0.0004934 ***	SDN	6.0325	1.2872	4.6867	2.777e-06 ***
DZA	9.2959	1.7086	5.4406	5.309e-08 ***	SLB	3.9655	2.8199	1.4063	0.1596376
ECU	8.4192	1.6813	5.0077	5.508e-07 ***	SLE	1.0560	2.7791	0.3800	0.7039575
EGY	7.6628	1.7924	4.2751	1.911e-05 ***	SUR	4.3718	1.7191	2.5430	0.0109895 *
ETH	3.5804	1.2471	2.8711	0.0040903 **	SYR	5.8485	2.8643	2.0419	0.0411647 **
GAB	13.4492	1.6773	8.0185	1.110e-15 ***	TKM	35.0834	4.3005	8.1579	4.441e-16 ***
GHA	4.4989	1.5237	2.9526	0.0031510 **	TTO	11.6830	1.7914	6.5217	6.950e-11 ***
GIN	4.3285	1.2218	3.5428	0.0003959 ***	TZA	3.2565	1.2688	2.5667	0.0102678 *
GUY	3.1234	2.0586	1.5172	0.1292158	UGA	2.9691	1.2026	2.4690	0.0135507 *
IDN	8.3909	2.4951	3.3629	0.0007712 ***	UKR	6.5681	2.4402	2.6917	0.0071095 **
IRN	13.5323	1.8154	7.4540	9.059e-14 ***	VEN	10.9953	1.8773	5.8569	4.716e-09 ***
KAZ	14.3851	2.0447	7.0355	1.986e-12 ***	VNM	7.0380	2.1493	3.2745	0.0010586 **
KWT	13.6334	2.2840	5.9691	2.385e-09 ***	YEM	9.2492	1.8741	4.9353	8.001e-07 ***
LBY	14.0581	3.2108	4.3784	1.196e-05 ***	ZAF	5.9148	1.9524	3.0295	0.0024497 **
MEX	5.0135	2.1489	2.3330	0.0196464 *	ZMB	6.9371	1.5852	4.3762	1.207e-05 ***
MLI	1.8678	1.2605	1.4818	0.1384044	ZWE	6.3079	1.8736	3.3667	0.0007608 ***
MNG	5.8754	1.5177	3.8712	0.0001083 ***					

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, $p < 0.1$

Time fixed-effects for regression 2 model 3

Year	Estimate	Std. Error	t-value	Pr(> t)	Year	Estimate	Std. Error	t-value	Pr(> t)
1993	7.90650	1.67243	4.7276	2.272e-06 ***	2003	9.10303	1.47057	6.1901	6.011e-10 ***
1994	6.55252	1.59253	4.1145	3.880e-05 ***	2004	9.70565	1.50598	6.4447	1.158e-10 ***
1995	6.12417	1.51726	4.0363	5.429e-05 ***	2005	11.45381	1.46311	7.8284	4.885e-15 ***
1996	7.32671	1.47140	4.9794	6.378e-07 ***	2006	9.17215	1.53038	5.9934	2.055e-09 ***
1997	5.29723	1.47777	3.5846	0.0003376 ***	2007	7.07221	1.50060	4.7129	2.442e-06 ***
1998	3.17199	1.44480	2.1955	0.0281307 *	2008	11.14032	1.47287	7.5637	3.908e-14 ***
1999	7.43566	1.40574	5.2895	1.226e-07 ***	2009	0.88103	1.52399	0.5781	0.5631915
2000	11.84488	1.34160	8.8289	< 2.2e-16 ***	2010	8.61754	1.42388	6.0522	1.429e-09 ***
2001	4.86934	1.43631	3.3902	0.0006985 ***	2011	8.23720	1.45218	5.6723	1.409e-08 ***
2002	5.31265	1.39714	3.8025	0.0001432 ***					

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, $p < 0.1$

Fixed-effects for regression 1 model 3

Country	Estimate	Std. Error	t-value	Pr(> t)	Country	Estimate	Std. Error	t-value	Pr(> t)
ARE	0.137722	0.132406	1.0402	0.2982680	MLI	0.020621	0.043185	0.4775	0.6329972
ARG	0.005682	0.042137	0.1348	0.8927325	MNG	0.024799	0.051510	0.4815	0.6301943
AZE	0.133058	0.056800	2.3426	0.0191520 *	MOZ	0.253672	0.049313	5.1441	2.687e-07 ***
BDI	0.128688	0.036584	3.5176	0.0004355 ***	MRT	0.161758	0.050725	3.1890	0.0014279 **
BHR	0.010127	0.062694	0.1615	0.8716708	MWI	0.113288	0.036619	3.0937	0.0019771 **
BOL	0.057338	0.043680	1.3127	0.1892945	MYS	0.285280	0.074126	3.8486	0.0001188 ***
BRN	0.146932	0.065732	2.2353	0.0253963 *	NGA	0.102899	0.048758	2.1104	0.0348240 *
BTN	0.344627	0.059989	5.7449	9.200e-09 ***	NOR	-0.045580	0.053238	-0.8561	0.3919150
CAF	0.074029	0.036351	2.0365	0.0417009 *	OMN	0.078097	0.050852	1.5358	0.1245948
CHL	0.224766	0.039837	5.6421	1.680e-08 ***	PER	0.258094	0.042190	6.1174	9.511e-10 ***
CHN	0.108826	0.052559	2.0705	0.0384010 *	PNG	0.095374	0.076310	1.2498	0.2113626
CMR	0.184386	0.041136	4.4824	7.382e-06 ***	QAT	0.054203	0.056665	0.9565	0.3387946
COG	0.100168	0.081969	1.2220	0.2217009	ROM	0.117805	0.049330	2.3881	0.0169355 *
COL	0.056607	0.036772	1.5394	0.1237044	RUS	0.095234	0.050529	1.8847	0.0594663 .
DZA	0.186146	0.040249	4.6249	3.748e-06 ***	SAU	0.052548	0.054655	0.9614	0.3363275

ECU	0.054990	0.035867	1.5331	0.1252411	SDN	0.251341	0.039225	6.4078	1.477e-10 ***
EGY	0.235598	0.040141	5.8692	4.379e-09 ***	SLB	0.149163	0.078670	1.8961	0.0579527 .
ETH	0.273660	0.040356	6.7811	1.193e-11 ***	SUR	0.239593	0.051998	4.6078	4.070e-06 ***
GAB	0.061321	0.057225	1.0716	0.2839173	SYR	0.173818	0.051051	3.4048	0.0006622 ***
GHA	0.264240	0.049439	5.3448	9.051e-08 ***	TTO	0.358338	0.057444	6.2380	4.432e-10 ***
GIN	-0.019378	0.045839	-0.4227	0.6724811	TZA	0.119381	0.040579	2.9420	0.0032613 **
GNB	0.125329	0.089352	1.4027	0.1607201	UGA	0.132163	0.035798	3.6920	0.0002225 ***
GUY	0.076490	0.068306	1.1198	0.2627950	UKR	0.299779	0.057822	5.1845	2.166e-07 ***
IDN	0.171572	0.051322	3.3431	0.0008286 ***	VEN	0.022651	0.044967	0.5037	0.6144593
IRN	0.076437	0.053122	1.4389	0.1501789	VNM	0.150752	0.054903	2.7458	0.0060368 **
KAZ	0.072800	0.058043	1.2542	0.2097540	YEM	0.227582	0.060683	3.7504	0.0001766 ***
KWT	0.078374	0.067139	1.1673	0.2430700	ZAF	0.271904	0.046875	5.8007	6.605e-09 ***
LBY	0.058522	0.138902	0.4213	0.6735194	ZMB	0.329288	0.044931	7.3287	2.323e-13 ***
MEX	0.136337	0.054407	2.5058	0.0122159 *	ZWE	0.179348	0.053610	3.3454	0.0008216 ***

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, $p < 0.1$

Time fixed-effects for regression 1 model 3

Year	Estimate	Std. Error	t-value	Pr(> t)	Year	Estimate	Std. Error	t-value	Pr(> t)
1993	0.155434	0.043095	3.6067	0.0003101 ***	2003	0.169851	0.035388	4.7996	1.590e-06 ***
1994	0.141168	0.038997	3.6200	0.0002946 ***	2004	0.144462	0.036913	3.9136	9.094e-05 ***
1995	0.147694	0.037742	3.9133	9.106e-05 ***	2005	0.147589	0.037959	3.8881	0.0001010 ***
1996	0.132681	0.035406	3.7474	0.0001787 ***	2006	0.136387	0.039171	3.4819	0.0004979 ***
1997	0.145026	0.034234	4.2363	2.272e-05 ***	2007	0.148636	0.037822	3.9299	8.498e-05 ***
1998	0.148761	0.033117	4.4920	7.055e-06 ***	2008	0.160344	0.040051	4.0035	6.241e-05 ***
1999	0.104277	0.034205	3.0486	0.0022989 **	2009	0.153697	0.036357	4.2274	2.364e-05 ***
2000	0.136523	0.035942	3.7984	0.0001456 ***	2010	0.154959	0.036717	4.2204	2.439e-05 ***
2001	0.133005	0.034792	3.8229	0.0001319 ***	2011	0.126611	0.037430	3.3826	0.0007179 ***
2002	0.125153	0.033743	3.7091	0.0002080 ***					

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, $p < 0.1$

Regressions for the g2 sample

Fixed-effects for regression 2 model 1

Country	Estimate	Std. Error	t-value	Pr(> t)	Country	Estimate	Std. Error	t-value	Pr(> t)
AFG	-2.1395174	2.8027601	-0.7634	0.4452482	LBY	49.6057574	3.5681095	13.9025	< 2.2e-16 ***
ALB	-0.5982008	1.8179035	-0.3291	0.7421097	LSO	-4.8367429	2.7109409	-1.7842	0.0743982 .
ARE	18.6630387	3.1048886	6.0109	1.845e-09 ***	MDG	1.0363447	1.6519430	0.6273	0.5304305
ARG	7.5157863	2.0637387	3.6418	0.0002707 ***	MEX	4.8005878	2.1385208	2.2448	0.0247799 *
AUS	2.9239357	1.5372354	1.9021	0.0571615 .	MKD	0.6677869	2.0688722	0.3228	0.7468632
AZE	38.7802680	1.5879505	24.4216	< 2.2e-16 ***	MLI	-1.7242100	1.5535695	-1.1098	0.2670689
BDI	10.1722282	1.4815849	6.8658	6.613e-12 ***	MNG	7.4568384	1.7611028	4.2342	2.294e-05 ***
BEN	-1.2299521	1.6706639	-0.7362	0.4616056	MOZ	4.2905311	1.9972557	2.1482	0.0316968 *
BFA	2.9794136	1.6290977	1.8289	0.0674186 .	MRT	20.3716852	1.7679661	11.5227	< 2.2e-16 ***
BGD	4.5011809	1.8182263	2.4756	0.0133017 *	MWI	2.1795639	1.6144698	1.3500	0.1770101
BGR	-2.8667201	2.1522701	-1.3320	0.1828760	MYS	5.8038897	2.9184392	1.9887	0.0467347 *
BLR	-0.0992610	3.0222551	-0.0328	0.9737995	NAM	-4.2882812	1.9438055	-2.2061	0.0273751 *
BOL	14.3506739	1.7073775	8.4051	< 2.2e-16 ***	NER	-1.7001772	1.3747898	-1.2367	0.2162053
BRA	4.5099497	2.0692088	2.1796	0.0292906 *	NGA	27.1677909	1.4705179	18.4750	< 2.2e-16 ***
BRN	38.9474317	2.0028964	19.4456	< 2.2e-16 ***	NOR	9.2123002	1.7263486	5.3363	9.487e-08 ***
BTN	7.6895654	1.9840832	3.8756	0.0001064 ***	NPL	0.4928385	1.9138394	0.2575	0.7967828
BWA	-4.3296228	1.6922566	-2.5585	0.0105128 *	NZL	1.8509781	1.8784258	0.9854	0.3244336
CAF	1.7919960	1.3573141	1.3203	0.1867511	OMN	29.0036101	1.6207668	17.8950	< 2.2e-16 ***
CAN	2.4984367	2.0927619	1.1938	0.2325380	PAK	4.4620825	2.0867852	2.1383	0.0324959 *
CHL	10.2996730	1.7801926	5.7857	7.221e-09 ***	PER	6.2503181	1.8112653	3.4508	0.0005589 ***
CHN	8.9623013	2.8388645	3.1570	0.0015940 **	PNG	28.4719377	2.2748966	12.5157	< 2.2e-16 ***
CIV	3.7170456	2.1521787	1.7271	0.0841482 .	PRY	-1.2777826	1.7045606	-0.7496	0.4534801
CMR	11.1558398	2.0500409	5.4418	5.276e-08 ***	ROM	8.2683726	2.4905292	3.3199	0.0009004 ***
COG	48.6335761	2.1684508	22.4278	< 2.2e-16 ***	RUS	25.4019269	2.1375417	11.8837	< 2.2e-16 ***
COL	6.7304905	1.6726899	4.0238	5.728e-05 ***	RWA	-0.5071799	1.5342966	-0.3306	0.7409755
CUB	2.6171164	2.0548993	1.2736	0.2028058	SAU	39.4637720	1.4825265	26.6193	< 2.2e-16 ***

DZA	17.5485853	1.8781041	9.3438	< 2.2e-16 ***	SDN	9.6904541	1.4752403	6.5687	5.075e-11 ***
ECU	17.0877704	1.7346562	9.8508	< 2.2e-16 ***	SLB	6.9811935	3.5783963	1.9509	0.0510656 .
EGY	12.5078762	1.8681996	6.6951	2.154e-11 ***	SLE	-1.2281826	3.5287717	-0.3480	0.7278040
EST	-2.7559853	2.4223137	-1.1377	0.2552253	SUR	6.2796132	1.9426877	3.2324	0.0012274 **
ETH	4.1759302	1.4720131	2.8369	0.0045556 **	SWZ	3.5773861	3.6008685	0.9935	0.3204767
FJI	-3.1334940	2.1534936	-1.4551	0.1456486	SYR	19.4881996	3.5385844	5.5073	3.643e-08 ***
GAB	37.7955809	1.5443566	24.4734	< 2.2e-16 ***	TGO	-0.7218359	1.6046842	-0.4498	0.6528326
GHA	0.9838759	1.7313820	0.5683	0.5698581	THA	3.3195863	2.9493360	1.1255	0.2603616
GIN	6.5724759	1.4924725	4.4038	1.064e-05 ***	TKM	55.2144330	5.1712706	10.6772	< 2.2e-16 ***
GTM	1.8899686	2.2397565	0.8438	0.3987657	TTO	26.3099704	1.7285924	15.2205	< 2.2e-16 ***
GUY	-3.1478295	2.3758014	-1.3250	0.1851861	TUN	2.6598613	2.1009958	1.2660	0.2055130
HND	0.3822536	2.0804997	0.1837	0.8542240	TZA	0.9527662	1.4926717	0.6383	0.5232811
IDN	12.6918216	2.3968405	5.2952	1.189e-07 ***	UGA	2.5692712	1.4162910	1.8141	0.0696648 .
IND	3.5565386	1.7687049	2.0108	0.0443450 *	UKR	4.7965641	2.4430283	1.9634	0.0496034 *
IRN	32.9431926	1.8385934	17.9176	< 2.2e-16 ***	VEN	29.1385204	1.7915543	16.2644	< 2.2e-16 ***
JAM	-2.0845452	2.1546043	-0.9675	0.3333021	VNM	7.3773401	2.2637418	3.2589	0.0011184 **
KAZ	37.0520327	1.9230804	19.2670	< 2.2e-16 ***	YEM	25.1928955	2.0739841	12.1471	< 2.2e-16 ***
KEN	-0.0034435	1.7691159	-0.0019	0.9984469	ZAF	5.2321668	1.9915720	2.6272	0.0086102 **
KGZ	0.6898310	2.0386411	0.3384	0.7350784	ZMB	8.6747312	1.7346275	5.0009	5.706e-07 ***
KHM	-2.9719399	2.2709755	-1.3087	0.1906488	ZWE	5.6690853	2.0828408	2.7218	0.0064927 **
KWT	38.3510669	2.5447538	15.0706	< 2.2e-16 ***					

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, $p < 0.1$

Fixed-effects for regression 1 model 1

Country	Estimate	Std. Error	t-value	Pr(> t)	Country	Estimate	Std. Error	t-value	Pr(> t)
AFG	0.2157768	0.0758307	2.8455	0.0044341 **	KWT	0.1072038	0.0643625	1.6656	0.0957879 .
ALB	0.5409753	0.0418251	12.9342	< 2.2e-16 ***	LBY	0.0365299	0.1160517	0.3148	0.7529342
ARE	0.2138897	0.0927325	2.3065	0.0210814 *	LSO	0.2519506	0.0727891	3.4614	0.0005374 ***
ARG	0.0430761	0.0427543	1.0075	0.3136813	MDG	0.5667801	0.0377466	15.0154	< 2.2e-16 ***
AUS	0.1040304	0.0425654	2.4440	0.0145250 *	MEX	0.3080076	0.0507524	6.0688	1.288e-09 ***
AZE	0.2754202	0.0531692	5.1801	2.218e-07 ***	MKD	0.4643257	0.0481111	9.6511	< 2.2e-16 ***
BDI	0.2402501	0.0385405	6.2337	4.555e-10 ***	MLI	0.1344192	0.0447991	3.0005	0.0026955 **
BEN	0.5990013	0.0435875	13.7425	< 2.2e-16 ***	MNG	0.0432656	0.0537147	0.8055	0.4205487
BFA	0.2185885	0.0391508	5.5832	2.361e-08 ***	MOZ	0.5508310	0.0491278	11.2122	< 2.2e-16 ***
BGD	0.4939088	0.0397259	12.4329	< 2.2e-16 ***	MRT	0.2462879	0.0513773	4.7937	1.637e-06 ***
BGR	0.4094304	0.0563964	7.2599	3.875e-13 ***	MWI	0.2559012	0.0395783	6.4657	1.008e-10 ***
BHR	0.1380360	0.0626250	2.2042	0.0275127 *	MYS	0.5692181	0.0678664	8.3873	< 2.2e-16 ***
BLR	-0.0016794	0.0644148	-0.0261	0.9791997	NAM	0.0851023	0.0530297	1.6048	0.1085366
BOL	0.1499878	0.0434853	3.4492	0.0005623 ***	NER	0.1215929	0.0389985	3.1179	0.0018215 **
BRA	0.4187053	0.0486454	8.6073	< 2.2e-16 ***	NGA	0.1458714	0.0482538	3.0230	0.0025028 **
BRN	0.1985702	0.0590947	3.3602	0.0007788 ***	NOR	-0.0829480	0.0508930	-1.6299	0.1031327
BTN	0.8092509	0.0528381	15.3157	< 2.2e-16 ***	NPL	0.1980023	0.0544454	3.6367	0.0002761 ***
BWA	0.0608671	0.0525583	1.1581	0.2468282	NZL	0.2782324	0.0426671	6.5210	6.983e-11 ***
CAF	0.1707404	0.0386785	4.4143	1.013e-05 ***	OMN	0.1006940	0.0478666	2.1036	0.0354098 *
CAN	0.4828483	0.0497114	9.7130	< 2.2e-16 ***	PAK	0.1386993	0.0541837	2.5598	0.0104734 **
CHL	0.4808447	0.0389068	12.3589	< 2.2e-16 ***	PER	0.6002830	0.0390869	15.3577	< 2.2e-16 ***
CHN	0.3151759	0.0490253	6.4288	1.286e-10 ***	PNG	0.0944901	0.0707931	1.3347	0.1819624
CIV	0.4281517	0.0526979	8.1247	4.441e-16 ***	PRY	0.1184064	0.0465418	2.5441	0.0109563 *
CMR	0.3448431	0.0420928	8.1924	2.220e-16 ***	QAT	0.0755123	0.0563801	1.3393	0.1804589
COG	0.0757967	0.0742077	1.0214	0.3070587	ROM	0.2282745	0.0481190	4.7440	2.096e-06 ***
COL	0.1494729	0.0386208	3.8703	0.0001087 ***	RUS	0.1951497	0.0485683	4.0180	5.868e-05 ***
CUB	0.2365841	0.0573679	4.1240	3.724e-05 ***	RWA	0.4140179	0.0394311	10.4998	< 2.2e-16 ***
DZA	0.3531307	0.0395736	8.9234	< 2.2e-16 ***	SAU	0.0651964	0.0505421	1.2899	0.1970708
ECU	0.0897626	0.0378550	2.3712	0.0177293 *	SDN	0.5262276	0.0383877	13.7082	< 2.2e-16 ***
EGY	0.5210859	0.0392082	13.2902	< 2.2e-16 ***	SLB	0.4235925	0.0784401	5.4002	6.656e-08 ***
EST	0.6050074	0.0624252	9.6917	< 2.2e-16 ***	SLE	0.2078959	0.1059829	1.9616	0.0498091 *
ETH	0.5358355	0.0394574	13.5801	< 2.2e-16 ***	SUR	0.6206734	0.0497119	12.4854	< 2.2e-16 ***
FJI	0.5825541	0.0569720	10.2253	< 2.2e-16 ***	SWZ	0.5227450	0.0705510	7.4095	1.268e-13 ***
GAB	0.0632307	0.0532849	1.1867	0.2353644	SYR	0.2812837	0.0525201	5.3557	8.521e-08 ***
GHA	0.5940302	0.0468955	12.6671	< 2.2e-16 ***	TGO	0.4604392	0.0453069	10.1627	< 2.2e-16 ***
GIN	-0.0238925	0.0475899	-0.5021	0.6156317	THA	0.5025381	0.0569579	8.8230	< 2.2e-16 ***
GNB	0.1204304	0.0866880	1.3892	0.1647600	TKM	0.2622068	0.1573401	1.6665	0.0956144 .
GTM	0.4156329	0.0395506	10.5089	< 2.2e-16 ***	TTO	0.7205375	0.0502245	14.3463	< 2.2e-16 ***
GUY	0.1863379	0.0705443	2.6414	0.0082557 **	TUN	0.7414845	0.0453035	16.3671	< 2.2e-16 ***
HND	0.3674034	0.0465311	7.8959	2.887e-15 ***	TZA	0.2426000	0.0421156	5.7603	8.395e-09 ***
IDN	0.3795890	0.0476860	7.9602	1.776e-15 ***	UGA	0.2583195	0.0381023	6.7796	1.205e-11 ***
IND	0.1684772	0.0442744	3.8053	0.0001416 ***	UKR	0.6363864	0.0537973	11.8293	< 2.2e-16 ***

IRN	0.1412427	0.0539055	2.6202	0.0087881 **	VEN	0.0251356	0.0449954	0.5586	0.5764170
JAM	0.4384110	0.0510543	8.5872	< 2.2e-16 ***	VNM	0.2479243	0.0554885	4.4680	7.894e-06 ***
KAZ	0.0981810	0.0568029	1.7285	0.0839074 .	YEM	0.3885246	0.0620007	6.2665	3.694e-10 ***
KEN	0.7249720	0.0421854	17.1854	< 2.2e-16 ***	ZAF	0.5743098	0.0434247	13.2254	< 2.2e-16 ***
KGZ	0.5951369	0.0515830	11.5375	< 2.2e-16 ***	ZMB	0.6653065	0.0419499	15.8595	< 2.2e-16 ***
KHM	0.7694282	0.0529691	14.5260	< 2.2e-16 ***	ZWE	0.3082010	0.0512347	6.0155	1.794e-09 ***

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$; $p < 0.1$

Fixed-effects for regression 2 model 2

Country	Estimate	Std. Error	t-value	Pr(> t)	Country	Estimate	Std. Error	t-value	Pr(> t)
AFG	4.921513	2.596891	1.8952	0.0580718 .	LBY	56.217135	3.403653	16.5167	< 2.2e-16 ***
ALB	3.877688	1.692208	2.2915	0.0219348 *	LSO	0.008967	2.593889	0.0035	0.9972417
ARE	24.791300	2.962181	8.3693	< 2.2e-16 ***	MDG	4.549802	1.542525	2.9496	0.0031821 **
ARG	10.935987	1.932728	5.6583	1.529e-08 ***	MEX	9.661037	2.016088	4.7920	1.652e-06 ***
AUS	7.070254	1.416966	4.9897	6.047e-07 ***	MKD	5.178711	1.937807	2.6725	0.0075297 **
AZE	44.106973	1.530719	28.8145	< 2.2e-16 ***	MLI	2.059855	1.491988	1.3806	0.1673985
BDI	13.748476	1.347613	10.2021	< 2.2e-16 ***	MNG	11.435407	1.695931	6.7428	1.553e-11 ***
BEN	2.929582	1.561906	1.8756	0.0607040 .	MOZ	9.576282	1.860241	5.1479	2.635e-07 ***
BFA	7.223706	1.496892	4.8258	1.394e-06 ***	MRT	25.376287	1.667259	15.2204	< 2.2e-16 ***
BGD	7.852049	1.696903	4.6273	3.705e-06 ***	MWI	6.279244	1.493225	4.2052	2.609e-05 ***
BGR	2.342302	2.048131	1.1436	0.2527776	MYS	11.800224	2.809224	4.2005	2.663e-05 ***
BLR	6.182139	2.862191	2.1599	0.0307779 *	NAM	1.054059	1.819180	0.5794	0.5623096
BOL	18.474695	1.575349	11.7274	< 2.2e-16 ***	NER	2.542743	1.281818	1.9837	0.0472892 *
BRA	9.051099	1.928844	4.6925	2.699e-06 ***	NGA	31.776269	1.406402	22.5940	< 2.2e-16 ***
BRN	42.345763	1.907132	22.2039	< 2.2e-16 ***	NOR	13.786589	1.651198	8.3494	< 2.2e-16 ***
BTN	12.841014	1.881119	6.8263	8.715e-12 ***	NPL	4.685515	1.798274	2.6056	0.0091724 **
BWA	0.833261	1.611484	0.5171	0.6051025	NZL	5.356999	1.769275	3.0278	0.0024635 **
CAF	5.865298	1.257854	4.6629	3.117e-06 ***	OMN	32.490571	1.575362	20.6242	< 2.2e-16 ***
CAN	6.920075	1.994291	3.4699	0.0005206 ***	PAK	9.796280	1.896311	5.1660	2.392e-07 ***
CHL	14.480411	1.650730	8.7721	< 2.2e-16 ***	PER	10.231260	1.668993	6.1302	8.777e-10 ***
CHN	14.180875	2.677604	5.2961	1.183e-07 ***	PNG	31.737292	2.193476	14.4689	< 2.2e-16 ***
CIV	7.982508	2.029627	3.9330	8.390e-05 ***	PRY	2.815741	1.594748	1.7656	0.0774573 .
CMR	14.571108	1.916980	7.6011	2.931e-14 ***	ROM	11.696871	2.358105	4.9603	7.039e-07 ***
COG	53.983801	2.104346	25.6535	< 2.2e-16 ***	RUS	31.085532	1.971598	15.7667	< 2.2e-16 ***
COL	10.651868	1.529555	6.9640	3.307e-12 ***	RWA	4.101853	1.422108	2.8843	0.0039223 **
CUB	6.150550	1.932252	3.1831	0.0014571 **	SAU	43.621611	1.381892	31.5666	< 2.2e-16 ***
DZA	20.082245	1.781003	11.2758	< 2.2e-16 ***	SDN	13.784345	1.361015	10.1280	< 2.2e-16 ***
ECU	21.022778	1.593300	13.1945	< 2.2e-16 ***	SLB	13.090082	3.415969	3.8320	0.0001271 ***
EGY	16.592926	1.722524	9.6329	< 2.2e-16 ***	SLE	2.809040	3.393617	0.8277	0.4078165
EST	2.802259	2.343888	1.1956	0.2318683	SUR	9.334073	1.838420	5.0772	3.830e-07 ***
ETH	8.485518	1.375721	6.1681	6.914e-10 ***	SWZ	8.256163	3.419084	2.4147	0.0157469 *
FJI	1.854952	2.021279	0.9177	0.3587697	SYR	22.563558	3.389937	6.6560	2.813e-11 ***
GAB	41.315412	1.491729	27.6963	< 2.2e-16 ***	TGO	3.528484	1.518698	2.3234	0.0201597 *
GHA	5.570078	1.634402	3.4080	0.0006544 ***	THA	8.681608	2.791847	3.1096	0.0018732 **
GIN	10.297796	1.412385	7.2911	3.075e-13 ***	TKM	59.483443	4.967785	11.9738	< 2.2e-16 ***
GTM	6.877967	2.060782	3.3376	0.0008452 ***	TTO	30.598904	1.673861	18.2804	< 2.2e-16 ***
GUY	0.706497	2.314414	0.3053	0.7601683	TUN	7.314383	1.979172	3.6957	0.0002193 ***
HND	4.643514	1.953435	2.3771	0.0174493 *	TZA	5.250991	1.382719	3.7976	0.0001461 ***
IDN	17.434912	2.239811	7.7841	7.105e-15 ***	UGA	6.865054	1.311599	5.2341	1.658e-07 ***
IND	8.179345	1.642090	4.9811	6.324e-07 ***	UKR	10.071582	2.309143	4.3616	1.291e-05 ***
IRN	36.287784	1.728482	20.9940	< 2.2e-16 ***	VEN	32.957820	1.650725	19.9657	< 2.2e-16 ***
JAM	2.801162	2.014793	1.3903	0.1644385	VNM	13.310089	2.143890	6.2084	5.353e-10 ***
KAZ	42.524419	1.797212	23.6613	< 2.2e-16 ***	YEM	30.602564	1.944606	15.7372	< 2.2e-16 ***
KEN	3.914625	1.649780	2.3728	0.0176531 *	ZAF	9.580126	1.853785	5.1679	2.368e-07 ***
KGZ	5.752084	1.920966	2.9944	0.0027501 **	ZMB	12.740703	1.626064	7.8353	4.663e-15 ***
KHM	2.664022	2.142812	1.2432	0.2137807	ZWE	9.848895	1.933538	5.0937	3.511e-07 ***
KWT	41.691487	2.451912	17.0037	< 2.2e-16 ***					

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$; $p < 0.1$

Time Fixed-effects for regression 2 model 2

Year	Estimate	Std. Error	t-value	Pr(> t)	Year	Estimate	Std. Error	t-value	Pr(> t)
1992	13.2966	1.6276	8.1693	2.220e-16 ***	2002	11.0865	1.2998	8.5296	< 2.2e-16 ***
1993	14.9058	1.5123	9.8566	< 2.2e-16 ***	2003	12.3225	1.3409	9.1897	< 2.2e-16 ***

1994	13.4472	1.4319	9.3913	< 2.2e-16 ***	2004	13.4894	1.3715	9.8353	< 2.2e-16 ***
1995	10.9704	1.3754	7.9761	1.554e-15 ***	2005	14.9223	1.3420	11.1193	< 2.2e-16 ***
1996	11.7259	1.3486	8.6951	< 2.2e-16 ***	2006	16.5455	1.3419	12.3300	< 2.2e-16 ***
1997	10.9556	1.3417	8.1657	2.220e-16 ***	2007	15.7610	1.3232	11.9116	< 2.2e-16 ***
1998	9.3141	1.3185	7.0643	1.614e-12 ***	2008	17.0096	1.3088	12.9959	< 2.2e-16 ***
1999	10.4639	1.3038	8.0259	1.110e-15 ***	2009	11.4400	1.2892	8.8738	< 2.2e-16 ***
2000	12.9767	1.2967	10.0077	< 2.2e-16 ***	2010	12.6729	1.2886	9.8350	< 2.2e-16 ***
2001	11.9302	1.3134	9.0833	< 2.2e-16 ***	2011	12.1335	1.3263	9.1483	< 2.2e-16 ***

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, $p < 0.1$

Fixed-effects for regression 1 model 2

Country	Estimate	Std. Error	t-value	Pr(> t)	Country	Estimate	Std. Error	t-value	Pr(> t)
AFG	0.214759	0.076390	2.8113	0.0049335 **	KWT	0.106124	0.069655	1.5236	0.1276135
ALB	0.539128	0.042500	12.6855	< 2.2e-16 ***	LBY	0.035467	0.120446	0.2945	0.7684037
ARE	0.211906	0.095133	2.2275	0.0259162 *	LSO	0.248073	0.074493	3.3302	0.0008679 ***
ARG	0.038832	0.043810	0.8864	0.3754121	MDG	0.565178	0.038398	14.7190	< 2.2e-16 ***
AUS	0.100524	0.043524	2.3096	0.0209083 *	MEX	0.299845	0.052732	5.6862	1.299e-08 ***
AZE	0.272956	0.059011	4.6255	3.737e-06 ***	MKD	0.460094	0.049554	9.2848	< 2.2e-16 ***
BDI	0.239223	0.039431	6.0669	1.304e-09 ***	MLI	0.132454	0.045719	2.8971	0.0037659 **
BEN	0.597426	0.044093	13.5491	< 2.2e-16 ***	MNG	0.041090	0.055677	0.7380	0.4605104
BFA	0.217166	0.039683	5.4725	4.437e-08 ***	MOZ	0.548137	0.050292	10.8991	< 2.2e-16 ***
BGD	0.492689	0.040146	12.2726	< 2.2e-16 ***	MRT	0.245017	0.054242	4.5171	6.269e-06 ***
BGR	0.402395	0.058465	6.8826	5.876e-12 ***	MWI	0.254441	0.040364	6.3036	2.908e-10 ***
BHR	0.134825	0.066719	2.0208	0.0433010 *	MYS	0.558840	0.072240	7.7358	1.021e-14 ***
BLR	-0.011193	0.067103	-0.1668	0.8675249	NAM	0.081140	0.054177	1.4977	0.1342175
BOL	0.147488	0.045244	3.2598	0.0011149 **	NER	0.119563	0.039607	3.0187	0.0025386 **
BRA	0.411960	0.049975	8.2433	2.220e-16 ***	NGA	0.144099	0.051834	2.7800	0.0054363 **
BRN	0.196223	0.063875	3.0720	0.0021262 **	NOR	-0.089563	0.053452	-1.6756	0.0938213 .
BTN	0.807725	0.054390	14.8507	< 2.2e-16 ***	NPL	0.196691	0.054998	3.5763	0.0003485 ***
BWA	0.057562	0.053709	1.0717	0.2838417	NZL	0.274161	0.043731	6.2693	3.628e-10 ***
CAF	0.168378	0.039444	4.2688	1.966e-05 ***	OMN	0.097746	0.053135	1.8396	0.0658299 .
CAN	0.475473	0.051657	9.2044	< 2.2e-16 ***	PAK	0.137083	0.054819	2.5006	0.0123970 *
CHL	0.478736	0.040257	11.8920	< 2.2e-16 ***	PER	0.599083	0.039718	15.0833	< 2.2e-16 ***
CHN	0.308052	0.050803	6.0637	1.331e-09 ***	PNG	0.090950	0.074546	1.2201	0.2224426
CIV	0.422312	0.054349	7.7704	7.772e-15 ***	PRY	0.116541	0.047608	2.4479	0.0143682 *
CMR	0.343090	0.043108	7.9589	1.776e-15 ***	QAT	0.074361	0.060865	1.2217	0.2218093
COG	0.071295	0.081305	0.8769	0.3805448	ROM	0.221761	0.049868	4.4470	8.709e-06 ***
COL	0.147584	0.039375	3.7482	0.0001781 ***	RUS	0.190069	0.051874	3.6641	0.0002482 ***
CUB	0.235263	0.057888	4.0641	4.822e-05 ***	RWA	0.413140	0.039818	10.3758	< 2.2e-16 ***
DZA	0.352303	0.042122	8.3638	< 2.2e-16 ***	SAU	0.063830	0.055616	1.1477	0.2510921
ECU	0.088323	0.039529	2.2344	0.0254553 *	SDN	0.525619	0.039250	13.3916	< 2.2e-16 ***
EGY	0.519950	0.040307	12.8998	< 2.2e-16 ***	SLB	0.422259	0.079717	5.2969	1.178e-07 ***
EST	0.596076	0.065384	9.1165	< 2.2e-16 ***	SLE	0.206937	0.106670	1.9400	0.0523824 .
ETH	0.535120	0.040135	13.3330	< 2.2e-16 ***	SUR	0.619352	0.050462	12.2737	< 2.2e-16 ***
FJI	0.580212	0.058115	9.9838	< 2.2e-16 ***	SWZ	0.518001	0.072402	7.1545	8.396e-13 ***
GAB	0.060996	0.058846	1.0365	0.2999467	SYR	0.279167	0.054794	5.0949	3.490e-07 ***
GHA	0.592236	0.047964	12.3476	< 2.2e-16 ***	TGO	0.458032	0.046380	9.8756	< 2.2e-16 ***
GIN	-0.025283	0.048702	-0.5191	0.6036599	THA	0.493519	0.059562	8.2858	2.220e-16 ***
GNB	0.118838	0.087304	1.3612	0.1734509	TKM	0.260073	0.161535	1.6100	0.1073941
GTM	0.413758	0.040205	10.2912	< 2.2e-16 ***	TTO	0.717556	0.054881	13.0748	< 2.2e-16 ***
GUY	0.182501	0.072982	2.5007	0.0123965 *	TUN	0.736289	0.046976	15.6738	< 2.2e-16 ***
HND	0.364929	0.047696	7.6512	1.998e-14 ***	TZA	0.241283	0.042804	5.6369	1.731e-08 ***
IDN	0.373528	0.049719	7.5128	5.795e-14 ***	UGA	0.257092	0.038747	6.6351	3.242e-11 ***
IND	0.163787	0.045376	3.6096	0.0003067 ***	UKR	0.628551	0.056213	11.1817	< 2.2e-16 ***
IRN	0.140289	0.056737	2.4726	0.0134131 *	VEN	0.023438	0.047937	0.4889	0.6248898
JAM	0.436734	0.052023	8.3951	< 2.2e-16 ***	VNM	0.242587	0.058095	4.1757	2.971e-05 ***
KAZ	0.096056	0.061637	1.5584	0.1191326	YEM	0.387694	0.064530	6.0079	1.879e-09 ***
KEN	0.723311	0.042762	16.9149	< 2.2e-16 ***	ZAF	0.569393	0.044743	12.7258	< 2.2e-16 ***
KGZ	0.590944	0.053149	11.1186	< 2.2e-16 ***	ZMB	0.663341	0.043376	15.2928	< 2.2e-16 ***
KHM	0.766211	0.054174	14.1435	< 2.2e-16 ***	ZWE	0.305233	0.052523	5.8114	6.194e-09 ***

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, $p < 0.1$

Time Fixed-Effects for regression 1 model 2

Year	Estimate	Std. Error	t-value	Pr(> t)	Year	Estimate	Std. Error	t-value	Pr(> t)
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1992	0.359615	0.038014	9.4600	< 2.2e-16 ***	2002	0.312230	0.031457	9.9257	< 2.2e-16 ***
1993	0.330350	0.036406	9.0740	< 2.2e-16 ***	2003	0.326530	0.031927	10.2273	< 2.2e-16 ***
1994	0.327051	0.033185	9.8555	< 2.2e-16 ***	2004	0.314899	0.032896	9.5724	< 2.2e-16 ***
1995	0.325420	0.032166	10.1168	< 2.2e-16 ***	2005	0.338458	0.033498	10.1039	< 2.2e-16 ***
1996	0.349577	0.031141	11.2257	< 2.2e-16 ***	2006	0.331016	0.034379	9.6284	< 2.2e-16 ***
1997	0.341769	0.031015	11.0196	< 2.2e-16 ***	2007	0.326401	0.034203	9.5432	< 2.2e-16 ***
1998	0.341378	0.030697	11.1208	< 2.2e-16 ***	2008	0.323610	0.035329	9.1598	< 2.2e-16 ***
1999	0.312046	0.031475	9.9142	< 2.2e-16 ***	2009	0.341272	0.032873	10.3817	< 2.2e-16 ***
2000	0.306784	0.031979	9.5933	< 2.2e-16 ***	2010	0.342457	0.032903	10.4081	< 2.2e-16 ***
2001	0.309099	0.032024	9.6521	< 2.2e-16 ***	2011	0.320982	0.034096	9.4141	< 2.2e-16 ***

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, $p < 0.1$

Fixed-effects for regression 2 model 3

Country	Estimate	Std. Error	t-value	Pr(> t)	Country	Estimate	Std. Error	t-value	Pr(> t)
AFG	2.03909	1.85348	1.1001	0.2712713	LBY	14.72433	2.71603	5.4213	5.918e-08 ***
ALB	2.45796	1.21346	2.0256	0.0428077 *	LSO	2.74694	1.86815	1.4704	0.1414502
ARE	10.50765	2.15342	4.8795	1.063e-06 ***	MDG	2.33317	1.12692	2.0704	0.0384154 *
ARG	4.67508	1.41149	3.3121	0.0009258 ***	MEX	3.73756	1.48749	2.5127	0.0119822 *
AUS	3.09240	1.04060	2.9718	0.0029610 **	MKD	3.50134	1.40266	2.4962	0.0125526 *
AZE	13.64369	1.42502	9.5744	< 2.2e-16 ***	MLI	1.73605	1.06260	1.6338	0.1023077
BDI	4.78758	1.00264	4.7750	1.797e-06 ***	MNG	5.67420	1.22626	4.6272	3.706e-06 ***
BEN	1.56691	1.11490	1.4054	0.1598928	MOZ	4.22318	1.34463	3.1408	0.0016850 **
BFA	3.19194	1.08017	2.9550	0.0031265 **	MRT	11.49040	1.26352	9.0939	< 2.2e-16 ***
BGD	3.52491	1.25054	2.8187	0.0048219 **	MWI	3.06121	1.07708	2.8421	0.0044811 **
BGR	2.45861	1.48221	1.6587	0.0971683 .	MYS	6.04010	2.07407	2.9122	0.0035889 **
BLR	4.07999	2.09037	1.9518	0.0509619 .	NAM	1.84296	1.30872	1.4082	0.1590680
BOL	7.10118	1.19940	5.9206	3.207e-09 ***	NER	1.27096	0.91563	1.3881	0.1651144
BRA	3.27083	1.40335	2.3307	0.0197680 *	NGA	9.02980	1.21124	7.4550	8.993e-14 ***
BRN	12.80398	1.68286	7.6085	2.776e-14 ***	NOR	4.85459	1.22457	3.9643	7.360e-05 ***
BTN	4.53747	1.36685	3.3197	0.0009013 ***	NPL	1.93395	1.28363	1.5066	0.1319073
BWA	1.58676	1.15171	1.3777	0.1682831	NZL	2.67904	1.29838	2.0634	0.0390774 *
CAF	2.29671	0.90568	2.5359	0.0112158 *	OMN	10.89384	1.33433	8.1643	2.220e-16 ***
CAN	3.28584	1.46628	2.2409	0.0250302 *	PAK	3.77757	1.37004	2.7573	0.0058287 **
CHL	5.85707	1.22280	4.7899	1.669e-06 ***	PER	4.46798	1.22111	3.6590	0.0002532 ***
CHN	5.51587	1.97820	2.7883	0.0052981 **	PNG	11.88685	1.67611	7.0919	1.322e-12 ***
CIV	4.03936	1.47331	2.7417	0.0061123 **	PRY	2.42884	1.16086	2.0923	0.0364144 *
CMR	5.72823	1.40627	4.0734	4.634e-05 ***	ROM	4.69055	1.72998	2.7113	0.0067014 **
COG	16.35055	1.87912	8.7012	< 2.2e-16 ***	RUS	8.99514	1.56794	5.7369	9.642e-09 ***
COL	4.26988	1.12486	3.7959	0.0001471 ***	RWA	1.72505	1.01666	1.6968	0.0897370 .
CUB	3.04763	1.38299	2.2037	0.0275482 *	SAU	14.43091	1.33986	10.7705	< 2.2e-16 ***
DZA	8.35944	1.37519	6.0788	1.211e-09 ***	SDN	5.11846	1.00456	5.0952	3.484e-07 ***
ECU	7.55169	1.21860	6.1970	5.754e-10 ***	SLB	3.49978	2.44279	1.4327	0.1519450
EGY	6.05213	1.27981	4.7289	2.257e-06 ***	SLE	1.16161	2.41002	0.4820	0.6298106
EST	2.69694	1.69570	1.5905	0.1117318	SUR	2.93996	1.32830	2.2133	0.0268746 *
ETH	2.79676	0.99465	2.8118	0.0049263 **	SWZ	6.13200	2.48270	2.4699	0.0135153 *
FJI	2.52677	1.44971	1.7429	0.0813424 .	SYR	5.70013	2.46056	2.3166	0.0205253 *
GAB	13.79113	1.34667	10.2409	< 2.2e-16 ***	TGO	2.19495	1.08770	2.0180	0.0435945 *
GHA	3.26357	1.17107	2.7868	0.0053226 **	THA	4.96450	2.06467	2.4045	0.0161948 *
GIN	4.21026	1.02271	4.1168	3.842e-05 ***	TKM	34.74128	3.61227	9.6176	< 2.2e-16 ***
GTM	3.60865	1.48672	2.4273	0.0152132 *	TTO	10.91411	1.36560	7.9922	1.332e-15 ***
GUY	2.57079	1.66323	1.5457	0.1221876	TUN	3.74558	1.44898	2.5850	0.0097387 **
HND	3.34808	1.41203	2.3711	0.0177342 *	TZA	2.46733	0.99190	2.4875	0.0128649 *
IDN	6.46884	1.68846	3.8312	0.0001275 ***	UGA	2.35693	0.94637	2.4905	0.0127564 *
IND	3.12569	1.20908	2.5852	0.0097329 **	UKR	4.61687	1.68525	2.7396	0.0061520 **
IRN	13.14445	1.41717	9.2751	< 2.2e-16 ***	VEN	10.27683	1.37244	7.4880	6.994e-14 ***
JAM	2.01329	1.43962	1.3985	0.1619671	VNM	6.09859	1.56589	3.8947	9.834e-05 ***
KAZ	14.18468	1.54584	9.1760	< 2.2e-16 ***	YEM	8.91238	1.52930	5.8277	5.618e-09 ***
KEN	2.12595	1.20770	1.7603	0.0783512 .	ZAF	4.08735	1.36286	2.9991	0.0027077 **
KGZ	3.83990	1.38370	2.7751	0.0055184 **	ZMB	5.52799	1.18512	4.6645	3.093e-06 ***
KHM	2.54245	1.54144	1.6494	0.0990665 .	ZWE	4.80273	1.40023	3.4299	0.0006037 ***
KWT	14.10558	1.92715	7.3194	2.491e-13 ***					

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, $p < 0.1$

Time fixed-effects for regression 2 model 3

Year	Estimate	Std. Error	t-value	Pr(> t)	Year	Estimate	Std. Error	t-value	Pr(> t)
1993	5.49547	1.13271	4.8516	1.225e-06 ***	2003	5.84217	0.99482	5.8726	4.290e-09 ***
1994	4.57820	1.07285	4.2673	1.978e-05 ***	2004	6.38745	1.02040	6.2598	3.855e-10 ***
1995	4.19973	1.01873	4.1225	3.747e-05 ***	2005	7.57799	1.00026	7.5760	3.553e-14 ***
1996	4.97936	1.00023	4.9782	6.418e-07 ***	2006	6.37586	1.02212	6.2379	4.436e-10 ***
1997	3.73695	0.99856	3.7423	0.0001823 ***	2007	5.02893	1.01409	4.9591	7.083e-07 ***
1998	2.35031	0.98111	2.3956	0.0165948 *	2008	7.50680	0.99291	7.5604	4.019e-14 ***
1999	5.14685	0.96134	5.3538	8.611e-08 ***	2009	0.91390	0.98880	0.9243	0.3553542
2000	7.79443	0.95620	8.1514	4.441e-16 ***	2010	5.76298	0.95799	6.0157	1.791e-09 ***
2001	3.50162	0.98901	3.5405	0.0003993 ***	2011	5.41324	0.98281	5.5079	3.631e-08 ***
2002	3.72796	0.97166	3.8367	0.0001247 ***					

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, $p < 0.1$

Fixed-effects for regression 1 model 3

Country	Estimate	Std. Error	t-value	Pr(> t)	Country	Estimate	Std. Error	t-value	Pr(> t)
AFG	0.162377	0.071511	2.2707	0.0231672 *	KHM	0.363692	0.049779	7.3061	2.749e-13 ***
ALB	0.279924	0.038161	7.3353	2.212e-13 ***	KWT	0.060706	0.061555	0.9862	0.3240285
ARE	0.134774	0.127439	1.0576	0.2902558	LBY	0.034093	0.132169	0.2580	0.7964426
ARG	0.014110	0.037436	0.3769	0.7062422	LSO	0.139902	0.068933	2.0295	0.0424045 *
AUS	0.045021	0.037287	1.2074	0.2272687	MDG	0.263823	0.035256	7.4831	7.261e-14 ***
AZE	0.119733	0.050731	2.3602	0.0182673 *	MEX	0.153737	0.046076	3.3366	0.0008482 ***
BDI	0.130988	0.033707	3.8860	0.0001019 ***	MKD	0.215523	0.043573	4.9463	7.565e-07 ***
BEN	0.323934	0.039950	8.1085	4.441e-16 ***	MLI	0.028115	0.040117	0.7008	0.4834141
BFA	0.096072	0.035002	2.7447	0.0060558 **	MNG	0.029263	0.047688	0.6136	0.5394554
BGD	0.229763	0.037022	6.2062	5.430e-10 ***	MOZ	0.265901	0.045104	5.8953	3.740e-09 ***
BGR	0.214628	0.050835	4.2221	2.421e-05 ***	MRT	0.156220	0.047074	3.3186	0.0009047 ***
BHR	0.011183	0.057063	0.1960	0.8446233	MWI	0.120363	0.034340	3.5051	0.0004565 ***
BLR	0.010023	0.057534	0.1742	0.8616953	MYS	0.313689	0.063616	4.9310	8.182e-07 ***
BOL	0.061086	0.038980	1.5671	0.1170881	NAM	0.046206	0.046526	0.9931	0.3206499
BRA	0.177123	0.044281	4.0000	6.334e-05 ***	NER	0.068945	0.033538	2.0557	0.0398100 *
BRN	0.134713	0.061332	2.1965	0.0280592 *	NGA	0.092146	0.045081	2.0440	0.0409528 *
BTN	0.356810	0.054366	6.5631	5.271e-11 ***	NOR	-0.037009	0.045834	-0.8075	0.4193965
BWA	0.044988	0.045844	0.9813	0.3264301	NPL	0.030057	0.062452	0.4813	0.6303194
CAF	0.080988	0.033535	2.4150	0.0157348 *	NZL	0.141748	0.037825	3.7475	0.0001786 ***
CAN	0.236632	0.045904	5.1550	2.536e-07 ***	OMN	0.067038	0.045494	1.4736	0.1406005
CHL	0.232240	0.035998	6.4515	1.107e-10 ***	PAK	0.062939	0.047351	1.3292	0.1837797
CHN	0.126078	0.044805	2.8140	0.0048936 **	PER	0.268449	0.037655	7.1291	1.010e-12 ***
CIV	0.222126	0.048210	4.6075	4.076e-06 ***	PNG	0.089539	0.071577	1.2509	0.2109530
CMR	0.191136	0.037468	5.1014	3.372e-07 ***	PRY	0.040010	0.040388	0.9906	0.3218687
COG	0.083574	0.074828	1.1169	0.2640480	QAT	0.041302	0.051652	0.7996	0.4239246
COL	0.062364	0.033653	1.8532	0.0638606 .	ROM	0.134172	0.042747	3.1387	0.0016969 **
CUB	0.058361	0.050733	1.1504	0.2499914	RUS	0.094673	0.044676	2.1191	0.0340846 *
DZA	0.180201	0.036740	4.9048	9.351e-07 ***	RWA	0.162903	0.036101	4.5124	6.410e-06 ***
ECU	0.052561	0.033399	1.5737	0.1155542	SAU	0.037077	0.048731	0.7608	0.4467497
EGY	0.240873	0.036378	6.6213	3.560e-11 ***	SDN	0.254056	0.035785	7.0996	1.251e-12 ***
EST	0.302533	0.058010	5.2152	1.837e-07 ***	SLB	0.155354	0.074887	2.0745	0.0380312 *
ETH	0.279728	0.037240	7.5115	5.840e-14 ***	SUR	0.249724	0.048486	5.1504	2.599e-07 ***
FJI	0.288243	0.054150	5.3230	1.021e-07 ***	SWZ	0.234454	0.063707	3.6802	0.0002330 ***
GAB	0.047229	0.051424	0.9184	0.3584031	SYR	0.171479	0.047633	3.6000	0.0003182 ***
GHA	0.277911	0.044564	6.2362	4.484e-10 ***	TGO	0.233185	0.041701	5.5918	2.248e-08 ***
GIN	-0.018026	0.042797	-0.4212	0.6736051	THA	0.236168	0.052995	4.4564	8.334e-06 ***
GNB	0.126295	0.086692	1.4568	0.1451631	TTO	0.360777	0.050292	7.1737	7.303e-13 ***
GTM	0.188188	0.035608	5.2849	1.257e-07 ***	TUN	0.362582	0.043992	8.2420	2.220e-16 ***
GUY	0.093055	0.062873	1.4800	0.1388632	TZA	0.127489	0.037194	3.4276	0.0006089 ***
HND	0.182073	0.042295	4.3048	1.671e-05 ***	UGA	0.137568	0.033402	4.1186	3.812e-05 ***
IDN	0.185750	0.044084	4.2136	2.513e-05 ***	UKR	0.321717	0.050318	6.3937	1.619e-10 ***
IND	0.070480	0.039170	1.7993	0.0719647 .	VEN	0.014548	0.040657	0.3578	0.7204814
IRN	0.063641	0.049285	1.2913	0.1966054	VNM	0.161183	0.050170	3.2127	0.0013148 **
JAM	0.163150	0.046357	3.5194	0.0004324 ***	YEM	0.219626	0.056999	3.8532	0.0001166 ***
KAZ	0.060690	0.052613	1.1535	0.2486980	ZAF	0.288754	0.040854	7.0679	1.573e-12 ***
KEN	0.338312	0.041489	8.1542	4.441e-16 ***	ZMB	0.338657	0.040239	8.4161	< 2.2e-16 ***
KGZ	0.310603	0.048934	6.3473	2.191e-10 ***	ZWE	0.191635	0.049499	3.8715	0.0001082 ***

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, $p < 0.1$

Time Fixed-Effects for regression 1 model 3

Year	Estimate	Std. Error	t-value	Pr(> t)	Year	Estimate	Std. Error	t-value	Pr(> t)
1993	0.192586	0.033932	5.6757	1.381e-08 ***	2003	0.171771	0.028707	5.9837	2.181e-09 ***
1994	0.143885	0.031672	4.5429	5.548e-06 ***	2004	0.153102	0.029395	5.2084	1.905e-07 ***
1995	0.185652	0.030335	6.1200	9.357e-10 ***	2005	0.161499	0.029790	5.4212	5.921e-08 ***
1996	0.176188	0.028649	6.1498	7.759e-10 ***	2006	0.165124	0.030485	5.4166	6.074e-08 ***
1997	0.162242	0.028167	5.7600	8.414e-09 ***	2007	0.164994	0.030305	5.4444	5.197e-08 ***
1998	0.180375	0.027663	6.5204	7.014e-11 ***	2008	0.163414	0.031379	5.2078	1.910e-07 ***
1999	0.132417	0.028209	4.6942	2.677e-06 ***	2009	0.179203	0.029262	6.1241	9.121e-10 ***
2000	0.155780	0.029105	5.3524	8.680e-08 ***	2010	0.159359	0.029393	5.4217	5.903e-08 ***
2001	0.156408	0.028670	5.4555	4.884e-08 ***	2011	0.151786	0.030153	5.0339	4.806e-07 ***
2002	0.154714	0.028000	5.5255	3.285e-08 ***					

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, $p < 0.1$

APPENDIX I

Metadata for the econometric regressions

We use three databases for our dataset. International trade data used to build the *gl1*, *gl2* and *gl4* variables are extracted from the COMTRADE¹ database. We use the WITS² extractor from the World Bank to select the product range. We use the HS 1988/92 database and extract the available UNCTAD SoP1 to SoP4 bundles for years 1992 to 2011. Those bundles are aggregated data on imports and exports. Bundle SoP1 is for raw materials, SoP2 for intermediate goods and SoP4 for capital goods. We extract exports and imports value for those three bundles for the 94 countries composing sample *g2* (see the list below). Sample *g2* is composed of countries earning more than 2% of GDP in natural resources rent on average between 1992 and 2011. Sample *g5* follows the same rule with a threshold at 5%, which gives a total of 60 countries (see the list below). We then compute the values for the Grubel-Lloyd index using the formula presented in chapter 4:

$$GL_{i,t} = \frac{(X_{i,t} + M_{i,t}) - |X_{i,t} - M_{i,t}|}{X_{i,t} + M_{i,t}} = 1 - \frac{|X_{i,t} - M_{i,t}|}{X_{i,t} + M_{i,t}}; 0 \leq GL_{i,t} \leq 1 \quad (\text{I.1})$$

With $X_{i,t}$ the exports of country i in t , and $M_{i,t}$ the imports.

Data on the volume of trade as a percentage of GDP *vt*, the growth rate of GDP *gg* and the value-added in manufacturing as a share of GDP *man* are obtained from the World Development Indicators (WDI) available in the World Bank databank³. We extract data for those three series for the years 1992 to 2011. Data on commodities prices comes from the Global Economic Monitor (GEM) Commodities. We extract monthly data starting in January 1992 for the “All commodities price index”, with a reference year 2005=100. The index aggregates, Fuel, Non-Fuel, Food, Beverages, Industrial and Agricultural Inputs, Metals and Energy. We then compute a simple average per year for the index and to obtain a series of 20 points. Those values are then matched with all the countries in both samples. Finally, resources rents are obtained from the Wealth Accounting database from the World Bank databank. We extract total natural resources rents as a percentage of GDP for all the countries in both samples, for years 1992 to 2011.

1. <http://comtrade.un.org/>

2. <https://wits.worldbank.org/WITS/WITS/Restricted/Login.aspx>

3. <http://databank.worldbank.org/data/home.aspx>

Countries in sample g5

United Arab Emirates	Guinea	Qatar
Argentina	Guinea-Bissau	Romania
Azerbaijan	Guyana	Russia
Burundi	India	Saudi Arabia
Bahrain	Iran (Islamic Republic of)	Sudan
Bolivia	Kazakhstan	Solomon Islands
Brunei Darussalam	Kuwait	Sierra Leone
Bhutan	Lybian Arab Jamahiriya	Suriname
Central African Republic	Mexico	Syria
Chile	Mali	Turkmenistan
China	Mongolia	Trinidad and Tobago
Cameroon	Mozambique	Tanzania, United Republic of
Congo	Mauritania	Uganda
Colombia	Malawi	Ukraine
Algeria	Malaysia	Venezuela
Ecuador	Nigeria	Vietnam
Egypt	Norway	Yemen
Ethiopia	Oman	South Africa
Gabon	Peru	Zambia
Ghana	Papua New Guinea	Zimbabwe

Note that those lists contain more countries than were used in the regressions. This is because depending on missing data, some countries were dropped altogether during our econometric tests. The final list of countries contains a maximum of 50 countries for sample *g5* and 87 for sample *g2* at a time.

Countries in sample g2

Afghanistan	Colombia	Lesotho	Rwanda
Albania	Cuba	Madagascar	Saudi Arabia
United Arab Emirates	Algeria	Mexico	Sudan
Argentina	Ecuador	Macedonia	Solomon Islands
Australia	Egypt	Mali	Sierra Leone
Azerbaijan	Estonia	Mongolia	Suriname
Burundi	Ethiopia	Mozambique	Swaziland
Benin	Fiji	Mauritania	Syria
Burkina Faso	Gabon	Malawi	Togo
Bangladesh	Ghana	Malaysia	Thailand
Bulgaria	Guinea	Namibia	Turkmenistan
Bahrain	Guinea-Bissau	Niger	Trinidad and Tobago
Belarus	Guatemala	Nigeria	Tunisia
Bolivia	Guyana	Norway	Tanzania (United Republic of)
Brazil	Honduras	Nepal	Uganda
Brunei Darussalam	India	New Zealand	Ukraine
Botswana	Iran (Islamic Republic of)	Oman	Venezuela
Central African Republic	Jamaica	Pakistan	Vietnam
Canada	Kazakhstan	Peru	Yemen
Chile	Kenya	Papua New Guinea	South Africa
China	Kyrgyzstan	Paraguay	Zambia
Cote d'Ivoire	Cambodia	Qatar	Zimbabwe
Cameroon	Kuwait	Romania	
Congo	Libyan Arab Jamahiriya	Russia	

APPENDIX J

Robustness tests with sub-samples

We split our samples *g5* and *g2* in the year 2002, constituting four sub-samples covering the periods 1992-2002 and 2002-2012. Sample *g5* is split into two parts of 600 theoretical observations each. Sample *g2* is split into two parts of 960 observations each. The actual number of observations used in each model is mentioned at the bottom of the tables. As more observations are missing (mostly in developing countries) at the beginning of the period, sub-samples for years 2002-2012 are larger.

Model 1 to 5 for regression 1 sample *g5* 1992-2002

	Model 1	Model 2	Model 3	Model 4	Model 5
lag(rr)			0.257196* (0.104591)	0.767039*** (0.069825)	-0.218116 (0.223455)
gl1	-3.378113* (1.470511)	-2.636941+ (1.505893)	-2.800096+ (1.580480)	-6.832167 (4.366742)	-8.321342 (6.658232)
gl4	1.051416 (1.238534)	1.700555+ (0.891276)	0.776028 (0.894190)	4.094516 (5.475021)	-0.821696 (12.55616)
gg	0.003539 (0.053303)	0.016557 (0.060959)	-0.018004 (0.078956)	-0.011387 (0.174947)	0.107184 (0.134740)
man	-0.054241 (0.087312)	-0.018952 (0.106600)	-0.031576 (0.080420)	-0.201991 (0.356597)	-0.344761 (0.301670)
vt	0.061210** (0.021834)	0.059068** (0.018077)	0.057227+ (0.031220)	0.108457* (0.054894)	0.098449 (0.073651)
cp	0.367960*** (0.056233)				
(Intercept)				-1.99737 (7.832099)	15.95702* (7.790101)
R ²	.30451	0.037989	0.10749	0.7986	
Adj. R ²	0.25391	0.030805	0.086122		
Num. obs.	349	349	332	271	332 (30 instr.)

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, + $p < 0.1$

Model 1 to 5 for regression 2 sample g5 1992-2002

	Model 1	Model 2	Model 3	Model 4	Model 5
lag(gl1)			0.395079*** (0.096424)	0.772382 (0.081647)	0.434620 (0.283652)
rr	-0.004781*** (0.001014)	-0.004859*** (0.001101)	-0.003956*** (0.000520)	0.0033232 (0.0023946)	-0.004156* (0.0020396)
gl2	0.137644*** (0.039286)	0.132860*** (0.038073)	0.054292 (0.043133)	0.290216 (0.1725071)	0.087159 (0.152542)
gl4	0.044928 (0.055606)	0.035426 (0.052286)	-0.007097 (0.074294)	0.0573795 (0.133066)	0.155976 (0.105741)
vt	0.002093* (0.000822)	0.001932* (0.000927)	0.001231 (0.000753)	0.000253 (.001204)	0.000291 (0.000621)
(Intercept)				-0.049836 (0.120969)	0.148517 (0.114239)
R ²	0.065436	0.054475	0.18631	0.7392	
Adj. R ²	0.054712	0.044186	0.14512		
Num. obs.	360	360	294	237	294 (24 instr.)

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, + $p < 0.1$

Model 1 to 5 for regression 1 sample g2 1992-2002

	Model 1	Model 2	Model 3	Model 4	Model 5
lag(rr)			0.249630 ⁺ (0.149477)	0.759037*** (0.062919)	0.558484*** (0.059144)
gl1	-2.593402** (0.891837)	-2.034687* (0.859241)	-2.044342* (0.895652)	-6.322186* (3.226901)	-5.607611** (1.880661)
gl4	1.797912 ⁺ (1.026493)	2.140386* (0.834136)	1.443402 (1.059947)	5.39859 (3.650851)	1.594326 (1.505335)
gg	-0.000135 (0.025887)	0.002854 (0.030056)	-0.026970 (0.046040)	-0.080622 (0.108306)	-0.036411 (0.052346)
man	-0.109774 (0.074361)	-0.116203 (0.084960)	-0.125963 ⁺ (0.075562)	-0.470958** (0.173499)	-0.246007** (0.090552)
vt	0.043498*** (0.013050)	0.045138*** (0.012837)	0.036371 ⁺ (0.019760)	0.057225* (0.057254)	0.036411** (0.0132963)
cp	0.230779*** (0.035862)				
(Intercept)				5.201472 (4.065938)	6.6554*** (1.891659)
R ²	0.18718	0.031598	0.093618	0.8169	
Adj. R ²	0.1562	0.025915	0.075887		
Num. obs.	556	556	528	428	528 (40 instr.)

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, + $p < 0.1$

Model 1 to 5 for regression 2 sample g2 1992-2002

	Model 1	Model 2	Model 3	Model 4	Model 5
lag(gl1)			0.324733*** (0.093609)	0.704405 (0.142116)	0.606245*** (0.188466)
rr	-0.004365*** (0.000965)	-0.004422*** (0.000878)	-0.003685*** (0.000475)	-0.004796* (0.002436)	-0.0042834** (0.001844)
gl2	0.130977*** (0.037977)	0.129331*** (0.037983)	0.089184* (0.037157)	0.328922* (0.167532)	-0.053997 (0.121270)
gl4	0.047065 (0.052558)	0.043687 (0.046423)	-0.008714 (0.055585)	0.151462 (0.142116)	0.137901 (0.091789)
vt	0.001256* (0.000607)	0.001137 (0.000719)	0.000634 (0.000504)	-0.0003321 (0.001346)	0.0001545 (0.0007787)
(Intercept)				-0.030913 (0.114211)	0.185024 ⁺ (0.110125)
R ²	0.044857	0.039306	0.12488	0.6665	
Adj. R ²	0.037627	0.032357	0.098893		
Num. obs.	577	577	471	378	471 (41 instr.)

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, + $p < 0.1$

Model 1 to 5 for regression 1 sample g5 2002-2012

	Model 1	Model 2	Model 3	Model 4	Model 5
lag(rr)			0.626421*** (0.102039)	1.626745 (2.130158)	0.924466*** (0.116852)
gl1	-0.762479 (1.587943)	-2.656644 (1.714872)	-1.105699 (0.937732)	-13.69712 (53.46419)	-2.835927 (3.816486)
gl4	8.634755*** (2.278436)	6.842307** (2.261418)	6.005152* (2.650014)	47.38885 (139.1027)	23.48135 (15.141401)
gg	0.458047*** (0.091852)	0.274438*** (0.081951)	0.243397*** (0.071221)	0.248741 (0.836015)	0.278110* (0.141401)
man	-1.128516*** (0.124840)	-1.421493*** (0.096638)	-0.677803** (0.212587)	4.756719 (15.91052)	-0.724548 ⁺ (0.373814)
vt	0.027560 (0.027164)	0.023940 (0.023465)	-0.004773 (0.009714)	0.0113161 (0.073502)	-0.008754 (0.024355)
cp	0.038129* (0.017803)				
(Intercept)				-72.00606 (236.4328)	5.913669 (3.960782)
R ²	0.28194	0.15495	0.48787	.	
Adj. R ²	0.23989	0.12881	0.39732		
Num. obs.	409	409	361	304	361 (30 instr.)

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, + $p < 0.1$

Model 1 to 5 for regression 2 sample g5 2002-2012

	Model 1	Model 2	Model 3	Model 4	Model 5
lag(g11)			0.332381*** (0.092767)	0.657773*** (0.100133)	0.921503*** (0.108726)
rr	-0.001650* (0.000719)	-0.001714 (0.001434)	-0.000741 (0.000769)	-0.004003 (0.003190)	-0.000781 (0.000875)
gl2	0.146422*** (0.040304)	0.140647*** (0.040996)	0.088369*** (0.025637)	0.020692 (0.099231)	0.0054219 (0.067870)
gl4	0.235390*** (0.033007)	0.242735*** (0.033268)	0.135548 (0.076110)	0.425714 (0.291674)	-0.003080 (0.031939)
vt	-0.000183 (0.000101)	-0.000156 (0.000136)	-0.000119 (0.000140)	-0.000032 (0.000718)	0.000042 (0.0001885)
(Intercept)				0.072864 (0.177283)	0.031131 (0.054706)
R ²	0.059806	0.058339	0.16411	0.5975	1.000000
Adj. R ²	0.052117	0.049766	0.13656		
Num. obs.	490	490	423	361	423 (24 instr.)

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, + $p < 0.1$

Model 1 to 5 for regression 1 sample g2 2002-2012

	Model 1	Model 2	Model 3	Model 4	Model 5
lag(rr)			0.606277*** (0.118302)	0.917283*** (0.068018)	0.949489*** (0.031308)
gl1	-0.490777 (1.181813)	-0.618962 (1.143717)	0.624791 (0.670208)	0.059771 (3.020711)	-0.892778 (0.977407)
gl4	5.234963*** (1.247531)	4.687605*** (0.975195)	4.030676** (1.427341)	0.441138 (5.477811)	0.540586 (0.512113)
gg	0.306779*** (0.060629)	0.185930*** (0.051578)	0.151849** (0.046886)	0.106602 (0.107208)	0.073225 (0.0491274)
man	-0.513266*** (0.145822)	-0.595614*** (0.160177)	-0.206139* (0.099902)	-0.519696 (0.367724)	-0.068946* (0.029882)
vt	0.027037 (0.028277)	0.023380 (0.025852)	-0.008898 (0.011167)	-0.011822 (0.022509)	-0.000830 (0.014431)
cp	0.032234** (0.010462)				
(Intercept)				8.936551 (6.740742)	2.360863 (0.838273)
R ²	0.20419	0.071839	0.42185	0.8978	
Adj. R ²	0.17637	0.061245	0.3531		
Num. obs.	712	712	632	533	632 (40 instr.)

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, + $p < 0.1$

Model 1 to 5 for regression 2 sample g2 2002-2012

	Model 1	Model 2	Model 3	Model 4	Model 5
lag(g11)			0.321868*** (0.079908)	0.610818*** (0.100782)	0.770008*** (0.112790)
rr	-0.001340 (0.000720)	-0.001076 (0.001025)	-0.000796 (0.000686)	-0.003642 (0.003098)	-0.002304* (0.003098)
gl2	0.134044** (0.048356)	0.132334** (0.049186)	0.072933 (0.040394)	0.065574 (0.114364)	-0.066459 (0.111674)
gl4	0.204955*** (0.035514)	0.204997*** (0.035356)	0.150938* (0.069660)	0.643801* (0.275557)	0.027825 (0.050334)
vt	-0.000216 (0.000154)	-0.000201 (0.000180)	-0.000149 (0.000153)	-0.000193 (0.001005)	0.0009783 (0.001251)
(Intercept)				0.002908 (0.125096)	0.076897 (0.096590)
R ²	0.0466	0.044999	0.14683	0.3227	
Adj. R ²	0.040912	0.039006	0.12448		
Num. obs.	811	811	703	601	703 (41 instr.)

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, + $p < 0.1$

APPENDIX K

**Lists of countries and comparison
groups**

Former Soviet Republics:

Armenia
Azerbaijan
Belarus
Estonia
Georgia
Kazakhstan
Kyrgyzstan
Latvia
Lithuania
Moldova
Tajikistan
Ukraine
Uzbekistan

Eastern Europe (Former COMECON):

Bulgaria
Czech Republic
Hungary
Poland
Romania
Slovak Republic

Natural Resources abundant countries:

Algeria
Bahrain
Iran
Nigeria
Syria
United Arab Emirates (U.A.E)
Venezuela
Yemen

Control Group 1:

Algeria
Iran
Kyrgyzstan
Venezuela
Yemen

Target Group:

Azerbaijan
Russian Federation
Kazakhstan
Nigeria
Syria
Uzbekistan

Control Group 2:

Belarus
Latvia
Tajikistan
Ukraine

Control Group 3:

Armenia
Bulgaria
Estonia
Georgia
Latvia
Moldova
Romania
Tajikistan
United Arab Emirates (U.A.E)
Ukraine

Control Group 4:

Bahrain
Czech Republic
Hungary
Lithuania
Poland
Slovak Republic

Following our criteria (institutional ties and an average share of natural resources rent in GDP between 20 and 40% between 1998 and 2008, Russia being at 30%) this list should have been completed by Chad, Papua New Guinea and Turkmenistan. Those countries were excluded because of missing data. This gives us a total of 28 countries.

APPENDIX L

Cross-country comparisons and the counterfactual study in chapter 4

The 6 governance indicators used in table 4.9 are from the World Governance Indicators (WGI).¹ Those indicators are built as described in Kaufmann et al. (2010). For the needs of our synthetic indicator, we replace missing 1999 and 2001 values by the average values from years 1998, 2000 and 2002, two by two. The values for the composite index are displayed below. We have no other missing observations in the data required to build the composite index. Rankings are obtained by giving a value of 1 to the worst performer in the considered dimension and 28 to the best performer. We use electric power transmission and distribution losses to capture the impact of climate distance and maintenance policy in the country. Population density plays a similar role, but produces a different ranking, suggesting that both indicators are required. The final ranking is just the average of the index values per year, without any weighting.

ANS and rents data are extracted from the “Changing Wealth of Nations” (data website) database. Details on the computation of rents are available at this address. Other data can be found in the World Development Indicators (WDI) (data website). ANS are missing for the U.A.E, Uzbekistan, Nigeria and Yemen. Some years are missing for Algeria, Iran, Tajikistan, and the Slovak Republic. We compute net investment from the Gross Fixed Capital Formation (GFCF) and Gross National Income (GNI) data in constant 2005 USD, while the produced capital depreciation is obtained from ANS data. Depreciation of produced capital is then multiplied by the GNI in constant USD, then subtracted to the GFCF and divided by GNI to obtain net investment as a percentage of GNI.

1. available at <http://data.worldbank.org/data-catalog/worldwide-governance-indicators>

Ranking per year using the composite index

Country	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	averages	variances
Yemen	5.75	4.75	5.75	5	5.5	6.5	5.75	6.25	7.25	6.75	6.25	5.95454545	0.49793388
Venezuela	8	9	9.5	8.25	7	4.75	4.5	4.5	4.5	4.25	4.75	6.27272727	3.94834711
Algeria	6.5	6.5	6.25	6.5	8.5	8	8	9	7	6.5	6	7.15909091	0.95764463
Iran	10.25	10.25	9.5	9.5	8.75	9	8.25	7.25	6.75	5.75	6.25	8.31818182	2.30785124
Kyrgyzstan	10.25	10.75	10.5	10	8.25	7.75	7.25	7	7	7	6.75	8.40909091	2.38946281
Kazakhstan	9.25	7.5	8.75	9.5	9.25	9.25	9	9.25	9.75	9.75	10	9.20454545	0.40702479
Nigeria	8	8	8.75	8.5	9	8.75	9	10	9.75	12.75	15.25	9.79545455	4.55475207
Uzbekistan	10.25	13	10.25	10	9.75	9.5	9.75	9.75	9.75	9.5	9.5	10.0909091	0.91219008
Azerbaijan	9.75	10.25	10	11	9.5	9.5	9.25	10	10.75	10.25	11	10.1136364	0.33367769
Russia	10.5	9.75	9.25	10.25	11.5	10.5	10.25	9.25	10.5	10.75	10.5	10.2727273	0.39152893
Syria	9.5	8.5	9.25	10.75	12.25	11	11	11	10.5	11.5	11.25	10.5909091	1.08264463
Tajikistan	13.5	13.75	12.5	12.25	12.25	11.75	12.5	11.25	11.25	11.25	10.25	12.0454545	0.97520661
Belarus	13.25	13.75	13.5	12.5	13	13	13	12	11.75	12	13.75	12.8636364	0.45867769
Ukraine	14	13.5	12.5	13	13.25	13.5	14	14.5	14.75	14.5	14.25	13.7954545	0.45247934
Latvia	13.5	12.5	13.5	13.75	13	14	14.75	14.25	15	14.75	16	14.0909091	0.90082645
Estonia	12.25	13	16.5	14.75	16.25	17.25	17.5	18.25	17.75	17.25	16.75	16.1363636	3.52688595
Georgia	15.5	15.5	15	16.75	14.25	15.25	17	17	17.25	17.25	17.5	16.2045455	1.14566116
Bulgaria	17.75	16.5	16.75	17	17.25	17.5	16.75	17.25	17.5	17.25	17	17.1363636	0.12913223
Armenia	17	17.75	17.5	17.5	16.75	17.75	18	18.5	17.25	17	16.75	17.4318182	0.27376033
U.A.E	17.75	17.75	17.75	17.25	17.75	16.75	17.25	17.5	18	17.75	18.75	17.6590909	0.2303719
Romania	18.5	18.25	18	17.25	17.25	18.5	17.75	17.75	18	17.25	17	17.7727273	0.25516529
Moldova	18.5	18.75	18.5	18.75	17.75	17.75	17.75	17	17	17	17.25	17.8181818	0.45557851
Lithuania	19.75	19.25	18.75	19	19.5	20	20.5	20.5	20.75	20.75	20.5	19.8636364	0.41322314
Bahrain	20.75	21	20.5	20.5	21	21.75	21.25	21.25	20.75	20.5	16.25	22.7045455	1.94318182
Poland	23.5	24	24.25	23.25	22.75	22.75	21.5	21.75	22	21.75	22.25	22.7045455	0.8161157
Hungary	22.75	22.75	22.5	22.25	23	22.75	23	22.75	23	23.75	22.75	22.8409091	0.12809917
Slovak Rep.	23.75	24.5	25	25	25.5	25	25.75	25.5	25.25	25.5	26.25	25.1818182	0.39876033
Czech Rep.	26	25.25	25.25	26	26.25	26.25	25.75	25.75	26	25.75	25.25	25.7727273	0.13016529

Source: Author's calculations from the World Development Indicators (WDI) and the World Governance Indicators (WGI), the World Bank

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Colophon

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Soutenabilité et Commerce International

Résumé :

Nous étudions les liens entre commerce international et soutenabilité. D'un point de vue théorique, la soutenabilité est l'application de la théorie utilitariste à la théorie du capital. La soutenabilité se définit par une gestion équitable des *moyens* du développement. Il s'agit de préserver un certain niveau de consommation et de richesse tout en développant l'équité inter- et intragénérationnelle sous la contrainte du niveau socialement défini de substituabilité en valeur monétaire des composants de la richesse. Les gains à l'échange issus du commerce international doivent être épargnés et réinvestis dans la mesure où ils sont le fruit d'une réallocation des ressources au sein du pays considéré. La nature du commerce international a également un impact sur les sentiers de développement. La présence de rendements d'échelle croissants dans la division internationale des processus productifs a également un impact sur la soutenabilité. Nous montrons la façon dont les incitations venant du commerce international ont un impact joint sur la gestion des dotations dans les pays riches en ressources naturelles. Un commerce inter-industries dans les secteurs des biens intensifs en ressources naturelles est un signe probable d'un sentier de développement insoutenable. Nous proposons d'étudier les pays issus de l'Union Soviétique pour mieux comprendre les interactions entre institutions et soutenabilité. L'Épargne Nette Ajustée (ENA) en Russie évolue de concert avec celle des pays voisins, sans lien avec celle d'autres pays ayant une même dotation en ressources naturelles. Nous préconisons d'utiliser des études contrefactuelles pour évaluer les trajectoires de développement dans un contexte d'incertitude sur les niveaux réels de richesse globale. L'ensemble de ces éléments nous conduit à revisiter les logiques d'intégration économique dans une optique de soutenabilité. **Mots-clés** : Développement Durable, Soutenabilité, Changement Structurel, Commerce International, Croissance néoclassique, Économie des ressources naturelles, Institutions

Sustainability and International Trade

Abstract: We endeavour to explore the many ways by which international trade has an impact on sustainability. From a theoretical perspective, sustainability is the application of the utilitarian theory of value on capital theory, used to define the interactions between human-being and their environment. We show how sustainability can be understood as sound and equitable management of the means of development, preserving consumption and wealth over time while fostering intragenerational and intergenerational equity and controlling for money-value substitutability. We use Adjusted Net Savings (ANS) to assess how opening economies to trade alters development paths. We then show how international trade should lead to additional savings, as gains from trade resulting from resources reallocation should be reinvested and not consumed. We explore how the nature of trade impacts development paths, showing how increasing returns to scale in the international division of the production processes changes factor prices. This should lead to more gains from trade saved and reinvested. We investigate how institutions and trade incentives interact in hindering sustainable management of natural capital in resource abundant countries. We show how inter-industry trade in natural resources intensive goods might be a sign for unsustainable development paths. To better understand interactions between institutions and sustainability, we suggest the dislocation of the Soviet Union as a natural experiment. We show how the evolution of ANS in the Russian Federation is closely correlated with the neighbouring countries, regardless of resources abundance. Counterfactual studies should be used to monitor sustainable development in the wake of uncertainty and scarce data on comprehensive wealth depreciation. Those elements lead us to conclude on the necessity to reconsider the rationale for economic integration on sustainability lines.

Keywords: Sustainable Development, Sustainability, Structural Change, International Trade, Neoclassical Growth, Resource Economics, Institutions

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