Trois essais sur les Relations de Long Terme entre Croissance et Environnement

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Table des matières

Introduction

0.1 Avant Propos

L'impact des activités humaines sur l'environnement a pris une place de plus en plus importante dans les débats publics au cours des dernières décennies. Si ces débats ont été amorcés par les économistes classiques et plus particulièrement Malthus dans son *« Essai sur le Principe de Population »* (1798), ils ont connu un regain d'intérêt au début des années 1970s avec les travaux du Club de Rome. [1] Ainsi, le rapport *« The Limits to Growth »* (Meadows *et al.* , 1972) posait la question de la possibilité d'une croissance infinie dans un monde fini. Comme nous le montrerons au cours de cette introduction, si l'activité humaine peut dégrader l'environnement de différentes manières (sur-exploitation des ressources renouvelables, diminution des stocks de ressources non-renouvelables, pollution de l'air, de l'eau, perte de biodiversité, etc.) l'environnement impacte en retour les activités humaines, diminuant les possibilités de production et affectant le bien-être des agents. Les ressources limitées de la planète ont longtemps été vues comme la principale limite à la croissance, comme en attestent les débats entre le Club de Rome et les économistes néoclassiques au cours des années 70. La capacité limitée de la nature à absorber les déchets issus des activités humaines est ensuite apparue comme une contrainte pouvant également s'opposer à une croissance infinie. Les débats autour de la courbe de Kuznets

1. Il y a eu bien évidemment des contributions d'importance majeure entre ces deux périodes. On pourra citer, a titre d'exemple Hotelling (1931) pour l'économie des ressources non-renouvelables, Gordon (1954) et Shaefer (1955) pour les ressources renouvelables, Pigou (1920) pour son travail sur les externalités, etc.

environnementale attestent de la complexité de la relation entre développement et environnement. Pour certains, la croissance signifie une pollution toujours plus importante et une pression accrue sur les ressources naturelles, tandis que pour d'autres elle permet d'améliorer les conditions de production (moins de prélèvements de ressources et d'émissions de déchets) grâce au progrès technique, de s'adapter aux changements climatiques, de mieux faire face aux risques sanitaires...

En mobilisant l'analyse néoclassique, et plus particulièrement les théories de la croissance, cette thèse est constituée de trois articles qui ont pour objet commun de s'interroger sur les limites que l'environnement pourrait imposer à la croissance. Nous chercherons ainsi à améliorer la compréhension de certains aspects de la relation entre environnement et activités humaines. Plus spécifiquement, le premier chapitre analyse les interactions entre dette publique, espérance de vie, qualité de l'environnement et développement. Le second chapitre s'intéresse aux effets de la pollution provenant de l'exploitation de ressources non-renouvelables sur la soutenabilité de l'économie, tandis que le troisième chapitre est consacré à la malédiction des ressources. Au fil des analyses proposées, nous tenterons d'éclairer les débats publics en proposant des pistes de réflexion autour des politiques à mener.

Le reste de cette introduction sera organisé comme suit. Une première partie présentera la relation à double sens entre activités humaines et environnement. Loin de présenter de manière exhaustive tous les mécanismes à l'œuvre, cette partie exposera cette relation en ayant recours à des exemples concrets. Nous essayerons autant que possible de concentrer l'analyse sur des dimensions qui seront évoquées dans la suite de cette thèse. Aussi, de nombreux aspects de cette relation ne seront pas, ou que brièvement, évoqués. La seconde partie aura pour objet la présentation de chacun des chapitres.

0.2 Environnement et activités humaines : une relation à double sens

Dans cette section, nous présentons succinctement l'impact environnemental des activités humaines, avant de regarder comment l'environnement affecte en retour ces dernières.

0.2.1 L'impact environnemental des activités humaines

L'activité économique humaine peut se résumer à la production et à la consommation de biens et services. Cette activité utilise des ressources naturelles renouvelables (eau, air, faune et flore...), non-renouvelables (énergies fossiles, métaux...), et produit des déchets, qui peuvent être liquides, gazeux, ou solides.

L'activité économique nécessite des ressources...

La question de l'épuisement des ressources a longtemps été vue comme la principale limite à la croissance. Le progrès technique ayant suivi la révolution industrielle a permis aux hommes de se multiplier et de consommer davantage, exerçant une pression accrue sur les ressources de la planète. Ainsi, l'ONU estime que la moitié des forêts a été détruite au cours du XX^{eme} siècle. Outre la disparition des forêts, la déforestation cause la disparition de nombreuses espèces qui en dépendent. Ainsi, à titre d'exemple, on estime qu'environ 100000 tigres vivaient dans la nature dans les années 1900 contre 3890 en 2016. La pêche est un autre exemple de ressource sur-exploitée par l'homme. La commission européenne estime que 93% des stocks de poissons méditerranéens sont exploités à des niveaux ne garantissant pas leur conservation. Le développement technologique a aussi permis aux hommes de tirer parti des ressources non-renouvelables, notamment pour assurer leurs besoins énergétiques. Comme le montre la figure

1, la consommation d'énergie fossile a crû de manière exponentielle au cours du XX^{eme} siècle, renforçant les besoins de matières premières, pourtant disponibles en quantités limitées. Cette constatation est également vraie pour d'autres types de minerais, comme par exemple les métaux.

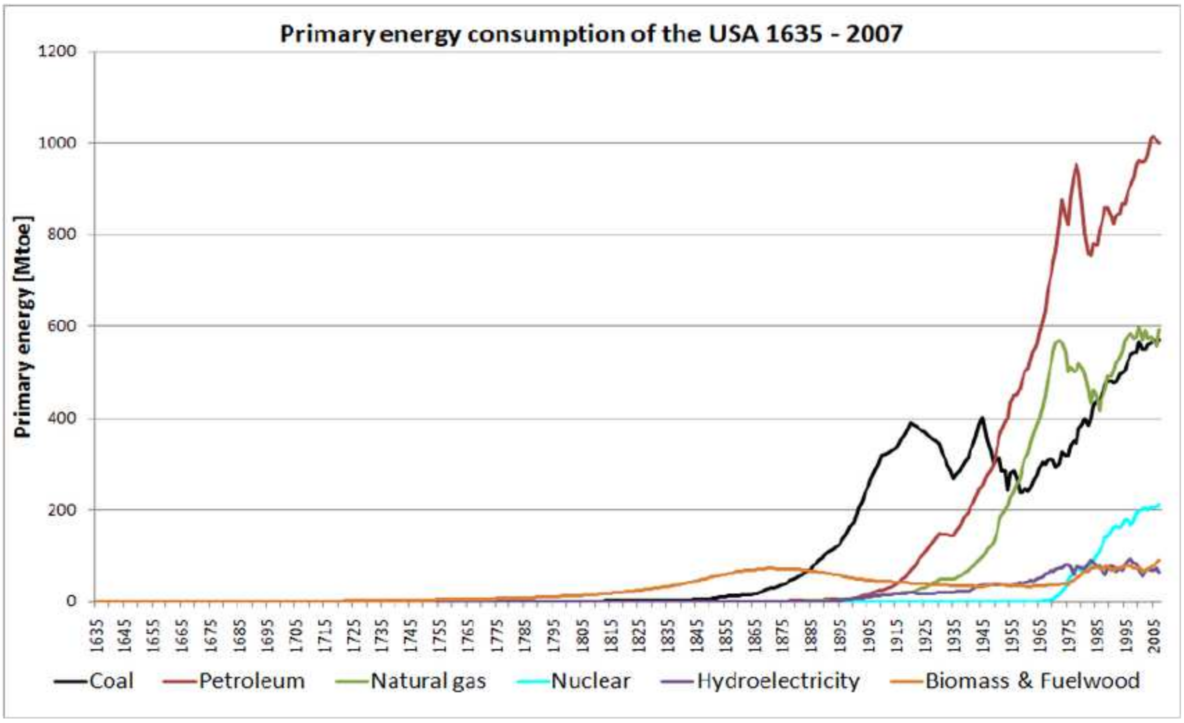

FIGURE 1 – Evolution de la consommation d'énergie primaire aux USA. Source : Höök & Aleklett (2009)

... et génère des déchets

En dehors de la question des ressources, les activités humaines sont également la source de déchets. Ils peuvent être solides (ordures ménagères, déchets nucléaires,...), liquide (hydrocarbures, huiles,...) ou encore gazeux (CO2, méthane,...). Certains de ces déchets peuvent être vus, à l'échelle de l'activité humaine, comme des flux, car se dégradant très vite, d'autres comme des stocks. Par exemple la combustion d'énergies fossiles génère à la fois du monoxyde et du dioxyde de carbone. Le monoxyde de carbone ayant une durée de vie très limitée dans l'atmosphère, il peut être vu comme un flux. Le dioxyde de carbone possède quant à lui une durée de vie très élevée : les émissions viennent augmenter les stocks qui diminuent en fonction des capacités d'absorption de la planète. Ainsi, une partie du CO2 généré par les activités humaines est capturée par les forêts et les océans. L'environnement agit donc comme un « puits » absorbant en partie les déchets issus des activités humaines. Ceci étant, certains déchets sont émis à un rythme supérieur à la capacité d'absorption de la planète et leur concentration dans l'atmosphère augmente alors. C'est le cas du CO2, représenté sur la figure 2.

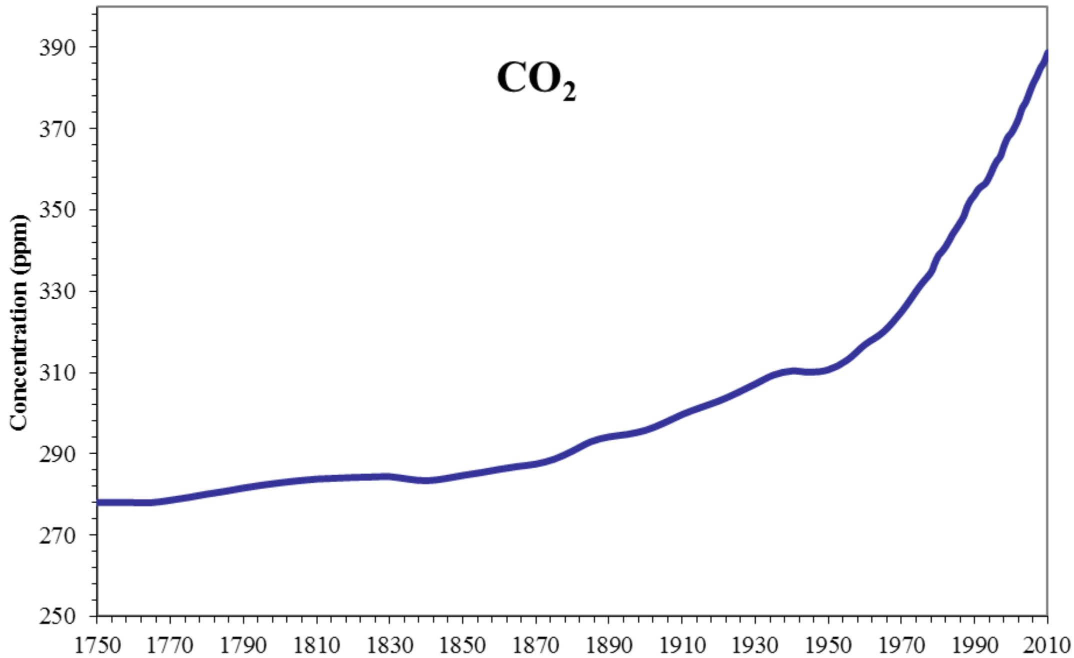

FIGURE 2 – Evolution de la concentration atmoshpérique en CO2. Source : European Evironment Agency

Les dimensions « source » et « puits » de l'environnement interagissent

Les interactions entre les dimensions *source* et *puits* de l'environnement exacerbent les effets environnementaux des activités humaines. La déforestation par exemple, loin de ne causer que la perte de ressources forestières et des espèces qui en dépendent, diminue également la capacité d'absorption de la pollution de la planète. De plus, si les arbres constituent en effet un puits de carbone, une fois abattus, ils le libèrent. D'après l'ONU, la déforestation pourrait être responsable d'une grande partie des émissions de CO2 d'origine anthropique (entre 12 et 20%) ce qui contribue au changement climatique, avec par exemple pour conséquence la montée des océans qui entraîne la perte d'une ressource rare : les terres émergées. Autre exemple, la pollution des rivières aux nitrates provenant de l'activité agricole entraîne un phénomène d'eutrophisation : le développement de micro-algues provoqué par les nitrates diminue l'oxygène dissous dans l'eau, et nuisent aux populations piscicoles. La présence de nitrates peut aussi être toxique pour la faune terrestre, amplifiant encore l'effet des nitrates sur les écosystèmes locaux, or la modification de ces écosystèmes est aujourd'hui l'une des principales responsables de la disparition d'espèces animales et végétales, donc de ressources potentielles. Ces exemples, et il en existe des centaines d'autres, illustrent bien les interactions possibles entre les dimensions *source* et *puits* de l'environnement.

Développement et environnement, une relation monotone ? La courbe de Kuznets environnementale

Le développement économique ayant suivi la révolution industrielle a été associé à une pression accrue sur les ressources ainsi qu'à d'importantes émissions de déchets. On peut néanmoins s'interroger sur le caractère monotone de cette relation. C'est ce que font Grossman & Krueger (1991) qui montrent que, après avoir contrôlé pour les autres déterminants non-économiques de la pollution, on trouve une relation en U inversé entre niveau de revenu par tête et qualité de l'environnement. Cette relation a été nommée courbe de Kuznets environnementale en référence aux travaux de Kuznets sur la relation en U inversé entre inégalités et niveau de revenu par tête.

La courbe de Kuznets environnementale peut s'expliquer par la combinaison de trois effets : un effet d'échelle, un effet de composition, et un effet technique (Grossman & Krueger, 1991).

L'effet d'échelle nous indique que, à composition de l'économie et techniques de production inchangées, une augmentation du revenu mènera à une hausse des émissions. Cependant, au fur et à mesure du développement, la composition de l'économie s'oriente vers des secteurs moins polluants. Partant d'un régime agricole, les économies développées sont aujourd'hui caractérisées par une structure productive orientée vers la production de services, après être passées par une phase industrielle intensive en pollution (Arrow *et al.* , 1995). Le progrès technologique permet également de faire diminuer les émissions grâce à l'utilisation de nouvelles technologies de production plus vertes, et en diminuant les coûts de maintenance environnementale. Dasgupta *et al.* (2002) estiment que les changements de composition de l'économie et des techniques de production, c'est-à-dire la transition vers une économie moins polluante, sont entrainés par une évolution des préférences des consommateurs qui valorisent l'environnement une fois un certain confort matériel atteint. La mise en place de dispositifs permettant de réduire la pollution est également facilitée par une bonne qualité institutionnelle, corrélée au développement.

Si la courbe de Kuznets environnementale est vérifiée, le développement économique peut alors être vu comme une option pour réduire l'impact environnemental des activités humaines (Beckerman, 1992). Certains vont même jusqu'à affirmer que, en restreignant le développement, les politiques environnementales auraient des effets contre-productifs. Néanmoins, plusieurs éléments s'opposent à cette vision. Tout d'abord, la croissance seule n'est pas suffisante pour faire baisser les émissions. Dinda (2004) remarque que « *In most cases where emissions have declined with rising income, the reductions have been due to local and national institutional reforms, such as environmental legislation and market-based incentives to reduce environmental degradation.* ». Ensuite, la courbe de Kuznets n'est vérifiée que pour des polluants locaux, tandis que les polluants globaux tels que le CO2 continuent d'entretenir une relation monotone avec le revenu. Le développement ne pourrait alors pas suffire, au moins à court terme, à réduire les émissions de tels polluants.[2] La baisse de pollution que l'on retrouve sur la courbe de Kuznets environnementale pourrait en outre s'expliquer par un déplacement des industries

2. Une interprétation de cette relation toujours monotone entre CO2 et revenu consiste à dire que le niveau de revenu correspondant au point de retournement pour le CO2 n'a pas encore été atteint.

polluantes vers des « havres de pollution ». Cette hypothèse semble être supportée par le fait que les changements des structures de production des économies développées ne sont pas accompagnés de changements équivalents des structures de consommation (Copeland & Taylor, 1995). Le caractère irréversible de certains dommage environnementaux pourrait également poser problème car ils ne pourront pas être réparés sur la partie décroissante de la courbe de Kuznets. Des mesures doivent donc être prise dès aujourd'hui pour éviter de tels dommages. Enfin, et de façon plus importante pour cette thèse, la pollution a des effets retours sur les activités humaines. La pollution pourrait alors être un frein au développement, entraînant des situations de trappes a pauvreté environnementales. Ces effets retours sont l'objet de la section suivante.

0.2.2 Impacts de l'environnement sur les activités humaines

Nous venons d'exposer brièvement les effets des activités humaines sur l'environnement. Il semble évident que l'environnement dans lequel se déroulent les activités économiques les impacte. Tout d'abord, l'environnement est un facteur de production, l'activité économique nécessitant des ressources naturelles. La pression exercée sur ces ressources peut alors poser problème quant au développement futur. La valorisation des ressources par les hommes peut aussi impacter le développement au travers de la malédiction des ressources. Des émissions de déchets importantes peuvent également être sources d'externalités importantes sur les autres facteurs de production : travail (au travers de la santé des agents), capital physique (catastrophes naturelles, suies,...) ou capital humain (difficultés d'apprentissage liées à la pollution,...). Enfin, en dehors de ses effets sur la production, la pollution affecte directement l'utilité des agents (valeur d'usage de l'environnement, santé, espérance de vie...). Cette section a pour objet l'exposition de ces différents canaux.

Épuisement des ressources et possibilités de croissance future

Les ressources naturelles sont essentielles dans le processus de production. Pétrole, charbon, métaux et autres sont autant d'intrants qui, combinés avec d'autres facteurs, parmi lesquels le travail et le capital, permettent de produire des biens et services finaux. Les ressources peuvent être classées en deux catégories : renouvelables et non-renouvelables. Les ressources non-renouvelables, de stocks finis, présentent un grand risque d'épuisement, qui peut parfois être dépassé grâce à l'utilisation d'un substitut alternatif renouvelable. L'exemple typique est l'énergie. Tandis que la production d'énergie repose aujourd'hui essentiellement sur la combustion (ou la fusion) d'énergies fossiles (principalement charbon, pétrole, gaz et uranium) soumises à risque d'épuisement, le développement de l'énergie solaire, éolienne, et hydraulique pourrait permettre de dépasser le problème de la disparition des combustibles fossiles. Toutefois, il convient de nuancer nos propos, la production du capital physique nécessaire à la production d'énergie non-fossile étant relativement intensive en ressources. [3] Parmi les ressources renouvelables, on distinguera les flux inépuisables, dont l'utilisation par l'homme ne provoque aucun risque sur leur disponibilité à venir, telles que les sources d'énergie solaire, éolienne et hydraulique, des stocks épuisables, constitués par l'ensemble des êtres vivants, et de l'eau. Les forêts par exemple, constituent une source d'énergie et de matériaux de construction qui se renouvelle. Cependant, une utilisation trop intensive des forêts nuit à son renouvellement en engendrant une dégradation des sols nécessaires à son développement, une disparition de l'habitat des agents de pollinisation (insectes, oiseaux, mammifères...), ainsi qu'une diminution de la quantité de pollen indispensable à sa reproduction. Les stocks de poissons constituent également un autre exemple de ressources renouvelables importantes. Ces stocks se renouvellent à un rythme dépendant de la capacité d'accueil du milieu, et de la taille du stock. Globalement, ces logiques s'appliquent aussi pour l'eau et l'ensemble des êtres vivants. Les prélèvements

3. La substituabilité possible entre les ressources naturelles et le capital physique est au cœur des débats entre les économistes néoclassiques, qui défendent une soutenabilité faible, et les tenants d'une soutenabilité forte. Pour synthétiser ces débats, l'hypothèse de soutenabilité faible implique que le capital naturel et les autres formes de capital sont substituables. La préservation du stock de capital naturel n'est donc pas une nécessité. Pour les tenants de la soutenabilité forte, le capital naturel doit être préservé car il est complémentaire aux autres formes de capital.

en ressources renouvelables pouvant être effectués par l'homme sont donc limités, et devraient prendre en compte ces contraintes de renouvellement.

On voit dès lors comment la diminution des stocks de ressources naturelles, renouvelables comme non-renouvelables, pourrait impacter les activités humaines. C'est de ce constat que part le « Club de Rome » dans son rapport *Limits to Growth* (Meadows *et al.* , 1972). La question de la possibilité de maintenir un niveau de consommation constant au moins égal au niveau actuel a ensuite été étudiée par Stiglitz (1974), Solow (1974) et Dasgupta & Heal (1974). Dasgupta & Heal (1979) résument l'ensemble des travaux théoriques (néoclassiques) disponibles à l'époque sur la question. Cette littérature a principalement montré que les conclusions pessimistes du Club de Rome pouvaient être dépassées sous certaines conditions. Pour synthétiser, si les ressources sont essentielles au processus de production, le progrès technologique, des possibilités de substitutions suffisantes, et l'existence de rendements croissants devraient permettre de dépasser le problème de la raréfaction des ressources naturelles.

Ressources et développement : la malédiction des ressources

Si la révolution industrielle a permis un développement rapide basé sur l'utilisation de ressources, la période d'après guerre est caractérisée par un phénomène nouveau : la malédiction des ressources. Sans nier le caractère essentiel des ressources dans le processus de développement, toute une littérature s'est développée pour chercher à expliquer pourquoi les pays riches en ressources avaient, en moyenne, des performances économiques inférieures à celles des pays pauvres en ressources.[4] Différents canaux ont été évoqués. Ils peuvent être classés en deux catégories, les canaux politiques d'un côté, les canaux économiques de l'autre.

Du côté des canaux économiques, le plus populaire est peut-être celui faisant référence au syndrome hollandais. La découverte et l'exportation de ressources naturelles provoquerait une

4. Il existe aussi toute une littérature cherchant à savoir s'il existe une telle malédiction. Nous ne rentrons pas ici dans ces débats. Le lecteur intéressé peut se référer au chapitre 3, ou à Van der Ploeg (2011).

sur-évaluation de la monnaie locale, causant une perte de compétitivité des secteurs secondaires et tertiaires, moteurs de la croissance. L'existence de ressources naturelles abondantes pourrait également évincer l'investissement en capital humain en augmentant les coûts d'opportunité de l'éducation. Un boom de ressources naturelles est également susceptible de rediriger l'investissement en capital physique des secteurs secondaire et tertiaire vers le secteur primaire. Dernier canal économique significatif, la volatilité des prix des matières premières causerait de l'instabilité macroéconomique, avec alors des effets négatifs pour l'investissement.

En ce qui concerne les canaux politiques, l'existence de rente pourrait permettre d'éviter ou de repousser des réformes structurelles impopulaires mais nécessaires. La rente pourrait aussi servir à réaliser des dépenses publiques improductives. La richesse en ressources naturelles est par ailleurs souvent associée à une faible qualité institutionnelle, or la qualité institutionnelle est l'une des caractéristiques essentielles du développement. Cette faible qualité institutionnelle peut se manifester au travers de la corruption, mais aussi à travers la présence de régimes autoritaires, qui, avec les rentes issues des ressources peuvent réprimer l'opposition, ou éviter de rendre des comptes. La faible qualité institutionnelle a en outre tendance à favoriser des comportements de recherche de rente par des groupes de pression cherchant à obtenir des transferts sans que ceux-ci ne soient liés à une quelconque contribution économique ou sociale. Enfin, les ressources peuvent générer des conflits. Des groupes rebelles peuvent en effet chercher à s'accaparer, ou à sécuriser une partie de la rente. Les opposants politiques peuvent aussi être amenés à s'opposer aux régimes autoritaires et aux inégalités qu'ils entrainent souvent en choisissant la lutte armée. Si les ressources ne sont pas toujours la source de conflits, elles peuvent néanmoins augmenter leur durée en procurant des ressources aux belligérants.

La pollution : des effets néfastes sur les facteurs de production

Si les ressources impactent le développement car elles constituent un intrant essentiel du processus de production ou encore à travers la malédiction des ressources, il en est de même de la pollution, qui peut avoir des effets sur les autres facteurs de production.

De très nombreuses études empiriques montrent que la pollution a des effets importants sur la santé que ce soit par la morbidité ou la mortalité. Par exemple Hart *et al.* (2011) montrent qu'une augmentation de $6\mu g/m^3$ de la pollution aux particules fines (PM_{10}) provoque une augmentation du risque de mortalité d'environ 4.3%.[5] La pollution de l'air n'est qu'un exemple, la pollution de l'eau, des sols, ainsi que la raréfaction des ressources naturelles (entrainant une modification des habitudes alimentaires) peuvent aussi impacter la santé des agents, de même que la multiplication d'événements climatiques extrêmes liés au changement climatique, que ce soit par l'impact direct de ceux-ci, ou du fait des épidémies ou de la destruction des infrastructures sanitaires qu'ils provoquent. La santé des agents est l'un des principaux déterminants de la croissance économique de long terme. La productivité des travailleurs est en effet largement déterminée par leur santé. Une mauvaise santé peut ainsi diminuer les capacités physiques et cognitives des agents (voir par exemple Hübler *et al.* , 2008 et Zivin & Neidell, 2012). En plus d'affecter la productivité des travailleurs, la pollution peut également impacter leur offre de travail (arrêts maladies...).

Outre les effets de la morbidité, une baisse de l'espérance de vie modifie également les comportements d'épargne, d'investissement, et d'éducation des agents, autant de composantes essentielles de la croissance de long terme. Ainsi, un individu avec une espérance de vie élevée aura une propension à épargner supérieure. L'augmentation de l'espérance de vie incite également à investir en capital humain. Outre les effets du développement sur la pollution exposés précédemment, la capacité des économies à s'adapter et à réduire l'impact d'un niveau donné de pollution sur la santé des agents dépend là aussi du niveau de développement atteint. A des stades de développement avancés, les connaissances techniques mais aussi les infrastructures (scientifiques, médicales...) peuvent aider à réduire l'impact de l'exposition des agents à des niveaux élevés de pollution. Ces arguments renforcent un peu plus la possibilité d'émergence

5. Ils montrent également qu'une augmentation de $6\mu g/m^3$ de $PM_{2.5}$ provoque une hausse de la mortalité de 3.9%. Une hausse de 4ppb (8ppb) de SO2 (NO2) est par ailleurs associée à un accroissement de la mortalité de 6.9% (8.2%).

de trappes à pauvreté environnementales.

La pollution peut également avoir des effets directs sur le capital physique, et sur la productivité globale des facteurs. Ainsi, les pluies acides détruisent le capital et amoindrissent par exemple les rendements agricoles, les catastrophes naturelles dont la fréquence augmente avec la concentration de gaz à effet de serre, détruisent l'appareil productif, les émissions de suies augmentent le taux de dépréciation du capital immobilier.

L'environnement comme source de bien-être

L'environnement est enfin une source de bien-être pour les agents. L'environnement procure en effet une valeur d'usage qui lui est propre. La qualité de vie associée à un environnement sain en est l'exemple caractéristique. En outre, l'environnement peut être vu comme un bien complémentaire à la pratique de certains loisirs. Il possède donc une valeur d'usage en ce qu'il permet la pratique de ces loisirs. On peut notamment penser à la randonnée ou à la pêche qui ne seraient possibles sans une qualité environnementale minimale. L'environnement a également une valeur de non-usage, en ce qu'il existe. Sous l'hypothèse que les agents sont altruistes envers les générations futures, l'environnement posséderait une valeur d'héritage, comme n'importe quel autre bien. On remarquera que la valeur associée à l'environnement et la valeur de legs qui en découle pourraient dépendre du stade de développement. En effet, on peut voir l'environnement comme un bien de luxe, qui commencerait à être valorisé par les agents une fois les besoins primaires atteints. La prise en compte de l'environnement pour sa valeur de non-usage par les agents dans leur utilité dépendant essentiellement de la sensibilisation à l'environnement reçue, le développement et l'éducation joueraient donc des rôles primordiaux dans l'établissement de « préférences vertes ». C'est là l'une des explications de la courbe de Kuznets environnementale, l'utilité des agents étant impactée directement à partir d'un certain seuil de développement, il est alors logique que ceux-ci changent leurs comportements une fois ce seuil atteint.

0.3 Présentation de la thèse

Les sphères économique et environnementale interagissent donc au travers de relations multiples et complexes. Les effets de l'environnement sur la croissance constituent-ils une limite à cette dernière ? Chacun des trois chapitres développés dans cette thèse a été écrit avec la volonté d'apporter des éléments de réponse à cette question. Cette section est dédiée à leur présentation.

0.3.1 Chapitre 1 : Dette publique, espérance de vie et environnement

Ce chapitre, dont la structure est résumée par la figure 3, part d'un constat simple : la protection de l'environnement tout comme la bonne gestion des finances publiques constituent des décisions de long terme, aux fortes implications intergénérationnelles. On pourrait dès lors imaginer des politiques de protection de l'environnement financées par endettement. Les générations futures devront certes rembourser la dette publique, mais elles jouiront d'un environnement de meilleure qualité. Cependant, un niveau d'endettement public déjà élevé, associé à des contraintes de stabilisation des finances publiques, dans l'esprit des critères de Maastricht, rendent ces choix politiques difficiles, voire impossibles. Le but de ce chapitre est de proposer des recommandations de politiques économiques visant à améliorer à la fois la qualité environnementale et le niveau de développement, dans un contexte de stabilisation de la dette publique.

Les choix de réduction de la dette publique et d'amélioration de la qualité environnementale dépendent de la valorisation du futur par les agents ou de façon équivalente de leur préférence pour le présent. Un agent rationnel avec une espérance de vie plus élevée sera plus enclin à reporter du bien-être présent au profit du bien-être futur, et cherchera donc davantage à protéger l'environnement. Ainsi, dans ce premier chapitre, la qualité environnementale sera directement introduite dans la fonction d'utilité des agents. Comme nous l'avons vu précédemment, la qualité environnementale est, en retour, l'un des déterminants essentiels de l'espérance de vie.

Dans ce chapitre, nous regardons s'il est possible d'augmenter à la fois le revenu et la qualité environnementale en présence d'une contrainte de stabilisation des finances publiques et lorsque l'on prend en compte la causalité à double sens entre espérance de vie et qualité environnementale. Pour ce faire, un modèle à générations imbriquées dans lequel l'environnement affecte l'utilité des agents de par ses valeurs d'usage et d'existence est développé.

Dans ce cadre, nous montrons qu'il peut exister des situations de trappes à pauvreté environnementales. Un environnement dégradé nuit à l'espérance de vie des agents. Ceux-ci n'entreprennent pas les dépenses de protection de l'environnement nécessaires pour réduire la pollution et n'investissent pas suffisamment, ce qui nuit au développement. Certains pays peuvent alors rester bloqués dans une situation caractérisée par une espérance de vie faible, un environnement dégradé, et un niveau de revenu peu élevé. Dans certains cas, une situation intermédiaire pourrait même exister. Dans ce chapitre, l'intérêt d'une politique environnementale volontaire est démontré. En effet, une augmentation de la maintenance publique favorise le développement et améliore les conditions environnementales. Nous montrons également que des échanges dette-contre-nature (une annulation d'une partie de la dette publique en échange de dépenses environnementales, accordés par une ONG ou un pays développé) peuvent aider les pays bloqués dans la trappe à en sortir. Enfin, en cas de sur-accumulation du capital, une augmentation de la dette publique pourrait permettre de ramener l'épargne à un taux optimal.

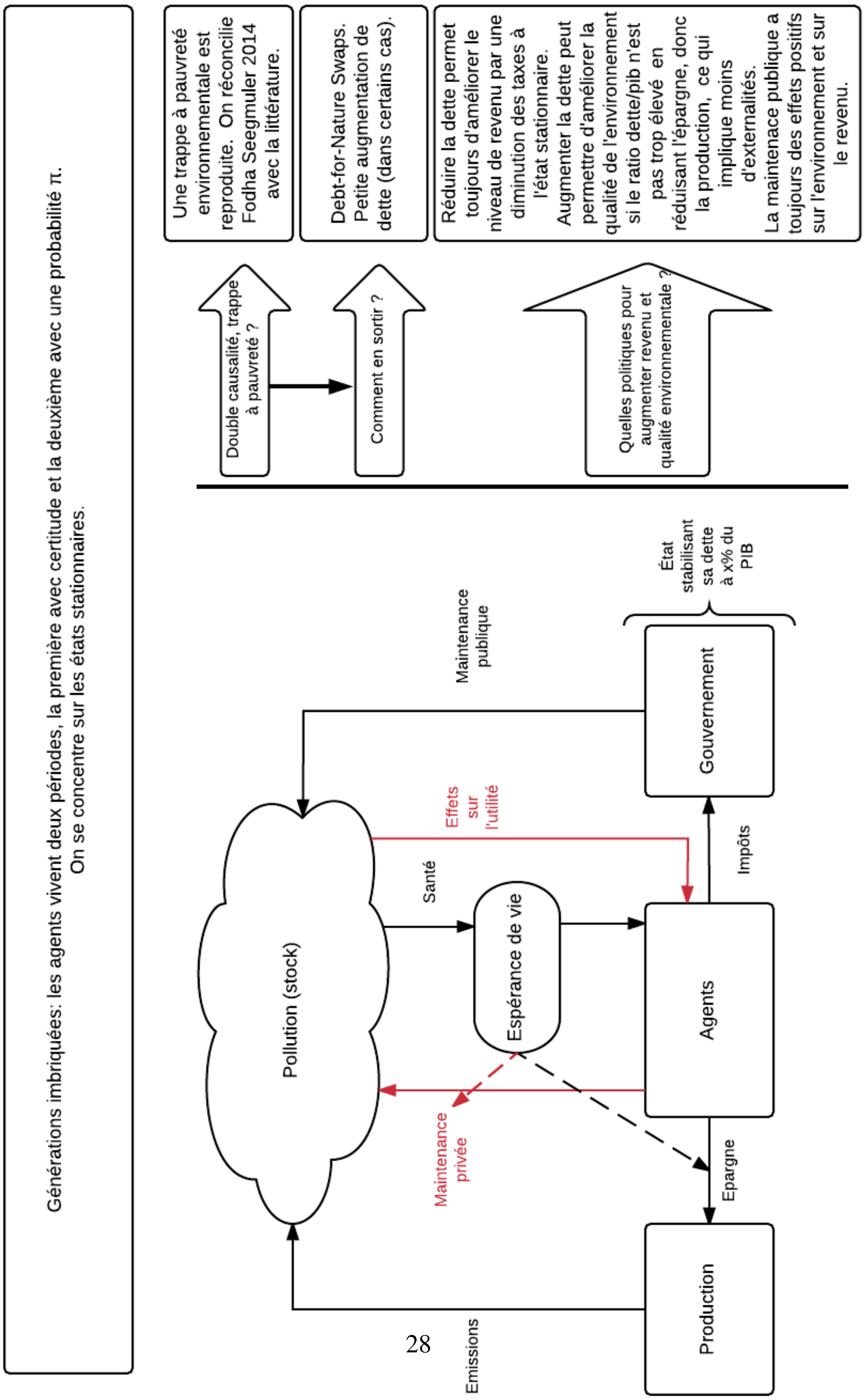

FIGURE 3 – Problématiques et résultats du chapitre 1

0.3.2 Chapitre 2 : Croissance dans une économie à générations imbriquées en présence d'une ressource non-renouvelable, essentielle, et polluante

Ce chapitre, dont la structure est résumée par la figure 4, est dédié à un autre type de relation entre environnement et croissance. Les ressources naturelles fossiles constituent un intrant essentiel dans le processus de production, et polluent. Comme elles sont épuisables, leur rareté croissante pourrait empêcher une croissance du revenu par tête dans le futur. La pollution qu'elles émettent peut en outre affecter la productivité globale, via des effets sur la santé des agents ou sur le stock de capital.

C'est l'une des problématiques posées par le Club de Rome. Les économistes néoclassiques ont su montrer que sous certaines conditions, à savoir principalement une croissance du niveau technologique à un taux exogène suffisamment élevé, une possible substitution entre capital naturel et capital physique ou humain, ou encore l'existence de rendements d'échelle croissants, la raréfaction des ressources n'empêcherait pas forcément la croissance. Cependant, pour démontrer leurs résultats, ils utilisent des modèles où les agents ont une durée de vie infinie, ce qui suppose un altruisme intergénérationnel parfait, or les travaux empiriques semblent montrer que cette forme d'altruisme dynastique est peu réaliste.

Ce chapitre prend le problème par un angle opposé. Nous développons un modèle à générations imbriquées où les agents sont supposés totalement égoïstes. Ce chapitre reprend, étend et développe le modèle de Agnani *et al.* (2005). L'extraction (ou l'utilisation de la ressource dans le processus de production) génère une pollution sous la forme de flux, c'est-à-dire que cette pollution disparaît à la fin de la période. Dans ce chapitre, la qualité de l'environnement n'est en revanche pas introduite dans la fonction d'utilité. Ainsi, l'environnement n'est pas valorisé directement par les consommateurs. Cependant celui-ci affecte la production de deux manières. Premièrement, les ressources naturelles (non-renouvelables) constituent un intrant essentiel au processus de production. Deuxièmement, les déchets que leur extraction et leur utilisation génère affectent la productivité globale des facteurs.

En se concentrant sur le sentier de croissance équilibré, nous retrouvons, comme Agnani *et al.* (2005) qu'une croissance de long terme positive est possible si la part du travail dans le revenu est suffisamment élevée, une condition n'existant pas dans les modèles à agents à durée de vie infinie. Le mécanisme sous-jacent est simple : les revenus du travail doivent être assez conséquents pour permettre une épargne suffisante pour compenser l'effet de la diminution progressive du stock de ressource.

Les effets de la pollution peuvent paraître surprenants de premier abord, néanmoins, ils sont assez intuitifs. Si la pollution heurte plus sévèrement la productivité, le niveau de revenu diminue, mais le taux de croissance de long terme (sur le sentier de croissance équilibré) augmente. Cela est dû au fait que la pollution est ici comptabilisée comme un flux : si elle heurte plus fortement la productivité, elle diminue aussi la contribution courante nette de la ressource dans la production. En résumé, plus la pollution associée à l'utilisation des ressources diminue la productivité des autres facteurs (santé, dépréciation du capital...), plus les firmes vont substituer du capital aux ressources dans le processus de production.

Si l'on peut suspecter l'existence de ressources non-renouvelables nécessaires et polluantes de constituer une limite à la croissance, nous montrons donc dans ce chapitre qu'un progrès technologique exogène couplé à des possibilités de substitutions suffisantes permettent d'atteindre un sentier de consommation non-décroissant. Par ailleurs, il est démontré que le type particulier de pollution considérée ici ne peut être vu comme une limite au développement.

Enfin, nous proposons dans ce chapitre deux stratégies alternatives pour décentraliser l'optimum social. La pollution de type flux ne créant pas de distorsions du sentier de croissance équilibré, un seul instrument sera nécessaire pour que l'économie atteigne le taux de croissance optimal. Dans un premier temps, nous caractérisons la taxe qui permettrait à une économie de marché d'atteindre le taux de croissance optimal lorsque les droits de propriété sont définis de manière privée. Néanmoins, les droits de propriétés sur les ressources minérales n'étant pas toujours définis de manière privée, nous caractérisons dans un second temps la politique d'extraction optimale que devrait suivre un monopole publique lorsque les droits de propriété du sous-sol appartiennent à la puissance publique.

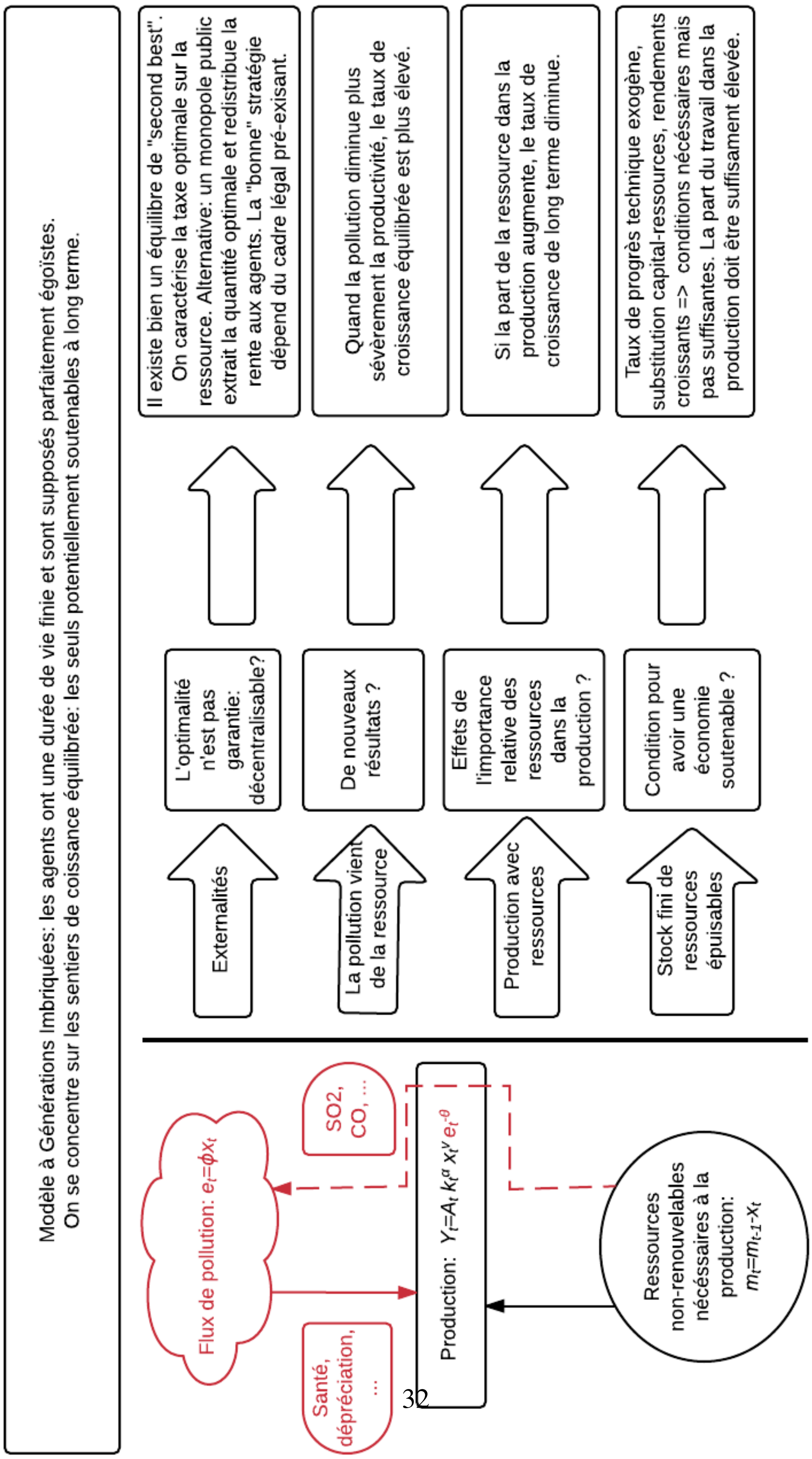

FIGURE 4 – Problématiques et résultats du chapitre 2

0.3.3 Chapitre 3 : Malédiction des ressources naturelles : un modèle à seuil

Le troisième chapitre est quant à lui dédié à une étude portant sur la malédiction des ressources. [6] Dans ce chapitre, l'approche choisie sera empirique. Il existe une littérature abondante traitant de ce sujet, synthétisée entre autre par Van der Ploeg (2011). Tandis que les premiers travaux montraient que les ressources naturelles affectaient négativement la croissance (Sachs & Warner, 1995) à travers différents canaux, la variable capturant l'abondance en ressource qu'ils utilisaient (la part des exportations de ressources naturelles dans le produit intérieur) a été très critiquée. Brunnschweiler & Bulte (2008) expliquent par exemple que ce ratio ne capture pas réellement l'abondance physique de la ressource, mais plutôt la dépendance de l'économie à cette ressource. Ces auteurs pointent aussi le fait que la dépendance à la ressource souffre probablement d'endogénéité une fois introduite dans une régression de croissance. En distinguant abondance et dépendance et en corrigeant le biais d'endogénéité, ils montrent qu'un pays abondant en ressource connaîtra, toutes choses égales par ailleurs, une croissance plus élevée, tandis que la dépendance n'aurait pas d'effet sur la croissance de l'économie.

Dans ce chapitre nous remettons en question ces résultats en modifiant la manière dont Brunnschweiler & Bulte (2008) prennent en compte l'hétérogénéité entre les pays. Tandis qu'ils introduisent simplement des indicatrices régionales, nous proposons de séparer les pays en fonction des conditions initiales de développement. Notre idée est que des pays répondront différemment à une variation de la dépendance ou de l'abondance à la ressource selon leur niveau de développement initial. Nous répondons ainsi à l'observation faite par Durlauf & Johnson (1995) qui remarquent que le modèle linéaire habituellement utilisé pour étudier la croissance n'est pas pertinent. Ils proposent à la place de grouper les pays en fonction de leurs conditions initiales, et de régresser ensuite par sous-groupes. Pour ce faire, ces auteurs recourent à un arbre

6. Ce chapitre a été écrit en collaboration avec Djamel Kirat, Laboratoire d'Économie d'Orléans, Université d'Orléans, UMR7322.

de régression.

En ce qui nous concerne, nous aurons recours à une méthodologie développée par Hansen (2000) qui a l'avantage de classer les pays en groupes définis de manière endogène par le modèle. La classification ne se fait donc pas selon des critères prédéfinis. Nous montrerons qu'il existe un seuil de développement initial séparant notre échantillon en deux groupes se comportant différemment. Ce seuil est ensuite estimé de manière endogène par le modèle. Enfin, nous estimons le modèle pour chacun de nos sous-groupes. Nous trouvons que les pays développés (ceux dont le PIB initial est supérieur au seuil) ne sont pas affecté par les ressources naturelles. En ce qui concerne les pays en développement, tandis que l'abondance en ressource semble favoriser le développement, la dépendance le freine. Nous alertons ensuite le lecteur sur les limites de l'analyse proposée, qui devrait notamment être complétée par des recherches futures analysant plus en profondeur la dimension temporelle des données.

Si, dans les pays en développement, la dépendance à la ressource freine la croissance, l'abondance semble avoir des effets positifs sur cette dernière. La dépendance pouvant être vue comme le résultat de choix économiques, nous pensons que des politiques de diversification de l'économie (consistant par exemple à réinvestir la rente issue de l'exploitation des ressources dans les secteurs secondaires et tertiaires) pourraient permettre de limiter le risque de subir une malédiction des ressource. Par ailleurs, nous suggérons qu'investir dans l'éducation, développer les institutions et les marchés financier pourrait permettre d'atténuer les effets des ressources sur le développement.

0.3.4 Synthèse des chapitres

Dans cette thèse, nous nous interrogeons sur les limites que l'environnement pourrait imposer à la croissance. Le premier chapitre montre que l'environnement peut constituer un frein au développement en diminuant l'espérance de vie des agents, en freinant leur épargne, et peut causer des situations de trappes à pauvreté environnementales. La mise en place de politiques environnementales publiques peut néanmoins permettre d'éviter ces trappes et d'augmenter le niveau de revenu par tête. Dans le second chapitre, l'existence de ressources non-renouvelables polluantes nécessaires à la production est susceptible de freiner la croissance. Cependant, dans la lignée des travaux néoclassiques des années 70, les difficultés liées au caractère fini des ressources peuvent être dépassées par un progrès technologique exogène et des possibilités de substitution capital-ressources suffisantes. Il est par ailleurs montré que le type de pollution particulière supposée dans le chapitre ne constituait pas un frein au développement. Enfin, le troisième chapitre démontre qu'une forte dépendance aux ressources naturelles affecte négativement la croissance des pays en développement, tandis que l'abondance en ressources naturelles la favorise. La dépendance étant le résultat de choix économiques, une politique de diversification de l'économie consistant à réinvestir les rentes issues de l'exploitation des ressources naturelles dans les secteurs secondaire et tertiaire pourrait permettre de la réduire. Par ailleurs, nous suggérons que développer l'éducation, les institutions et les marchés financiers pourrait permettre de limiter le risque de malédiction des ressources.

Chapitre 1

Public Debt, Life Expectancy and the Environment [1]

1.1 Introduction

Environmental care and the reduction of public debt are both linked to the future decisions of agents. Long-run fiscal objectives, such as reducing public debt and public budget deficits, may constitute a constraint on the promotion of environmental quality. Descriptive statistics show that the correlation coefficient between the mean of the Net General Government Debt ratio and the mean of the Environmental Performance Index (EPI) [2] was -0.161 for the period 2000-2010. [3] That seems to confirm that a high public debt may be a constraint on the environmental preservation.

The trade-off between environmental quality and public debt reduction depends on how

1. This chapter is essentially based on an article published in *Environmental Modeling & Assessment* as Clootens (2017). I would like to thank the journal for allowing reproduction in the thesis.
2. More details about the EPI may be found in Hsu *et al.* (2014).
3. It is significant at the 1% level. See Appendix 1 for more details about the statistics.

people value the future. A rational agent with high life expectancy will place a greater value on the future, and will be more willing to forego immediate welfare in favor of future gains. He/she will be more likely to decrease the public debt level and to preserve the environment. This argument is present in Ono & Maeda (2001) who introduce the idea of private maintenance based on life expectancy. Ono & Maeda (2002) show that under a perfect annuitization assumption, a higher life expectancy may promote both growth and environmental quality in an overlapping generations (OLG) framework.

Life expectancy is in turn determined by environmental quality. Indeed, the natural environment constitutes an important determinant of life expectancy through several channels, including climate, pollution, natural disasters, etc. For example, Laden *et al.* (2006) find that a $10\mu g/m^3$ increase in fine particulate air pollution gives rise to an additional mortality risk of approximately 15%. Jouvet *et al.* (2010) wrote one of the first papers studying the impact of environmental quality on life expectancy in an overlapping generations model.

Mariani *et al.* (2010) present two stylized facts about the relationship between life expectancy and the environment, which are positively correlated and both bimodally distributed. They argue that these stylized facts are compatible with – and give support to – the assumption of a two-way causality and the existence of an environmental poverty trap, a situation characterized by a low life expectancy, a poor environmental quality, and a low level of capital. Indeed, if the environment is a major determinant of life expectancy, which is in turn an important factor of both saving and environmental expenditures, some economies may be trapped in a vicious circle: a poor longevity implies low environmental maintenance, which leads to a high level of pollution that in turn keeps life expectancy low. Since life expectancy is an important determinant of saving, the economy may not be able to grow. Since Mariani *et al.* (2010) have shown that some countries may be trapped in this state, how such economies may escape from this trap seems to be a question of major importance.

This article aims to provide policy recommendations to improve both environmental quality and economic development. Notably, it studies how public debt and public maintenance may be used to escape from the environmental poverty trap. Since long run fiscal objectives impose monitoring public debt and deficits, the analysis is performed in the context of public debt consolidation, in the spirit of the Maastricht Treaty for the European Union which requires European countries to stabilize their public debt ratio at less than 60% of the GDP.[4] The methodology follows Diamond (1965) who discusses the role of public debt in an OLG model without the environmental dimension. This issue is also well discussed in De La Croix & Michel (2002). Considering constant public debt allows debt to be used as a policy instrument and ensures the long-run sustainability of the environmental policy.[5] Since this paper is mainly interested in steady states, this assumption leads to a constant public debt to GDP ratio, consistent with the existing literature. Indeed, in an endogenous growth model, Minea & Villieu (2010, 2013), among others, have shown that there exists a constant optimal public indebtedness ratio. According to Escolano (2010), markets and populations also place a high importance on a stable public debt to GDP ratio. Moreover, it will be shown that there exists an optimal ratio of public indebtedness as in Minea & Villieu (2010, 2013).

This question is linked to Fodha & Seegmuller (2014) who explicitly model a government that invests in environmental maintenance and consider the impact of environmental quality on life expectancy, but they do not consider private maintenance by consumers motivated by the enrichment of environmental quality. These authors find evidence for the possibility of an environmental poverty trap, but their article depicts a conflict between capital accumulation and environmental quality which is at odds with the rest of the literature.[6] Fodha & Seegmuller (2012) study public debt stabilization and environmental quality in an OLG model which takes into account both private and public maintenance, but they do not consider the impact of envi-

4. There are a lot of economies constrained by "budget balanced rules" or"debt rules" that have been set in order to consolidates public finances. The interested reader could refer to the IMF Fiscal Rule Dataset (Budina *et al.* , 2012).

5. It also simplifies the analysis since it allows an explosive debt path to be avoided.

6. Fodha & Seegmuller (2012), Mariani *et al.* (2010), John *et al.* (1995) find that there is no conflict between the environmental quality and development.

ronmental quality on life expectancy.

This chapter brings both public and private maintenance into a two periods OLG model which includes the existing two way causality between the environment and life expectancy found in Mariani *et al.* (2010). The environmental quality is supposed to evolve *à la* John & Pecchenino (1994). Such a framework allow policy recommendations to be made following Fodha & Seegmuller (2014), using a model in which there is no conflict between growth and the environment.

In Fodha & Seegmuller (2014), an increase in public maintenance is associated with a lower level of capital. In this paper, it will be shown that public maintenance promotes growth. Environmental policy thus becomes growth enhancing ! Consistent with the stylized fact presented in Mariani *et al.* (2010), an environmental poverty trap may exist. Public debt reduction associated with environmental expenditures (in the spirit of debt-for-nature swap) [7] may help a country to escape from the trap. Using a welfare analysis, it will be shown that public debt may be used to solve the capital over-accumulation problem, [8] and to reach an environmental target.

Section 2 presents the model, and Section 3 presents optimal choices and inter-temporal equilibriums. Section 4 studies the conditions related to the existence of equilibriums. Section 5 examines dynamics. Section 6 presents the comparative statics. Section 7 focuses on the welfare analysis, and finally the last section will conclude the findings.

7. A debt-for-nature swap is a mechanism that may be used by developing countries to finance an environmental policy. Broadly speaking, it consists in debt cancellation afforded in exchange for the commitment to invest in environmental maintenance. Further details may be found in Hansen (1989) or Deacon & Murphy (1997). Cassimon *et al.* (2011) propose a good case study of a US-Indonesian debt-for-nature swap.

8. In overlapping generations models, the first welfare theorem does not apply. The reader could refer to De La Croix & Michel (2002) for further explanations.

1.2 The model

An OLG model is used with infinite discrete time and three types of agents, consumers, firms and a government.

1.2.1 Consumers

Consumers live for one period with certainty, while their life expectancy in the second period is subject to some uncertainty. For the sake of simplicity, population growth is not considered, and the size of a young generation is normalized to one. In the second period of his/her life, while old, a consumer will live during $\pi(e_t) \in (0, 1)$. The aggregate preferences of households are represented by the following log-linear utility function:

$$U_t(c_t; e_{t+1}; d_{t+1}) = ln(c_t) + \pi(e_t)\gamma ln(e_{t+1}) + \pi(e_t)(1-\gamma)ln(d_{t+1}) \quad (1.1)$$

$\gamma \in (0; 1)$ represents how a consumer values the environment with respect to consumption in his/her second period of life (green preferences). It may be noticed that the environmental quality appears twice in the utility function, firstly in life expectancy and secondly as being directly valued by households. An agent can't improve its life expectancy which depends on choices done by previous generations. Thus agents longevity could be interpreted as an intergenerational environmental externality. [9]

During his/her life's first period, a consumer works and is remunerated at the competitive real wage w_t, he/she pays taxes $\tau_t \geq 0$. He/she consumes c_t and saves s_t. The consumer also spends m_t in environmental maintenance. During the second period of life, households use their savings plus interest to consume d_{t+1}. To avoid difficulties linked with an uncertain lifespan, we follow Blanchard (1984) and Chakraborty (2004) in assuming a perfect annuity market. We

9. This formulation is present in Mariani *et al.* (2010) in a different context.

thus suppose that all deposits are centralized in a mutual fund that invests in capital. The gross return of this fund is $\hat{R}_{t+1}$. Then, at the equilibrium, we obtain $\hat{R}_{t+1} = r_{t+1}/\pi(e_t)$. While the gross return of this fund is linked to the average life expectancy, savings decisions remain individual decisions. Thus, a consumer maximizes his/her utility (1) subject to the following budget constraints:

$$w_t - \tau_t = c_t + m_t + s_t \tag{1.2}$$

$$d_{t+1} = \frac{r_{t+1}}{\pi(e_t)} s_t \tag{1.3}$$

Combining (3.2) and (3.3) the inter-temporal budgetary constraint is:

$$w_t - \tau_t = c_t + m_t + d_{t+1}\frac{\pi}{r_{t+1}} \tag{1.4}$$

1.2.2 Firms

Firms produce goods with capital K_t and labor N_t according to a Cobb-Douglas production function $F(K_t, N_t)$. Because the population's size is normalized to one, $N_t = 1$. Thus $y_t = f(k_t)$ with $k_t = K_t/N_t = K_t$ such that:

$$y_t = f(k_t) = k_t^{\epsilon} \tag{1.5}$$

with $\epsilon \in (0, 1)$ as the capital share in production. Given standard profit maximization, the wage and the interest rate are obtained:

$$r_t = \epsilon k_t^{\epsilon - 1} \tag{1.6}$$

$$w_t = (1 - \epsilon) k_t^{\epsilon} \tag{1.7}$$

1.2.3 The government

Following Fodha & Seegmuller (2014), the government objective is to improve environmental quality through public spending G_t. This paper considers both public and private maintenance because there is the possibility that there are different types of pollution. Private maintenance is devoted to the fight against local pollution, while public maintenance is devoted to global pollution. Here aggregated pollution is considered, and these two types of maintenance are substitutes, while differing in their productivity. The implications of this assumption in the model should be discussed. Broadly speaking, global pollution may be analyzed as having impacts on human activities, while local pollution may be analyzed as having impacts on health. However, there is no doubt that extreme events play a role in life expectancy, leading directly to victims or indirectly via poverty, insalubrity and diseases that follow them. Moreover, the direct impact of global pollution on human activities (and income) decreases life expectancy. In this model, life expectancy is assumed to depend only on environmental quality (and not on income) for the sake of simplicity. Thus, this aggregation allows the impact of global pollution on life expectancy to be taken into account, whilst keeping the model simple.

It is assumed that public maintenance productivity $\rho \in (0, \infty)$ is higher than private maintenance productivity $\sigma \in (0, \infty)$ [10]:

Assumption 1: $\rho \geq \sigma$

To finance public spending, the government can use taxes, τ_t, or debt, B_t.[11] Because $N_t = 1\, \forall t$, the government budget constraint may be written in per capita terms. Thus, g_t and b_t represent per capita public spending and debt per capita, respectively. The fact that the gov-

10. If public maintenance's productivity is not higher than the private one, there is no reason to consider public maintenance in this framework because its use will be inefficient. Indeed, government will take resources from households to perform what households perform better. In 2013, one third of France's environmental expenditure was attributed to households. Moreover, coordination issues may make public maintenance more efficient than private maintenance. The likelihood of this assumption may be analyzed in further research.

11. The model doesn't take into account money so the debt is expressed in terms of a representative good of which price has been normalized to one. The debt is thus a real debt.

ernment can use debt to finance future environmental quality means that future generations will support the cost of future environmental quality, which corresponds to a type of beneficiary-payer principle. Current generations will also benefit from public maintenance because they will enjoy a better environmental quality when they will be in the latter period of their lives. But future generations will take advantage of better environmental quality in two ways: their utility as they become old, and a higher life expectancy. The inter-temporal budget constraint of the government is then:

$$b_t = r_t b_{t-1} + g_t - \tau_t \tag{1.8}$$

with $b_{-1} \geq 0$ given.

To avoid difficulties linked to explosive expenditure and debt, this paper follows Fodha & Seegmuller (2014) assuming that debt and public expenditure per worker are constant. This does not diminish the contribution of this paper which is mainly interested in steady states. The objective is to study how an economy which is at its steady state will be impacted by a change in the level of public debt in the long run. This approach comes from the seminal model of Diamond (1965). The economy thus follows a public debt stabilization constraint and (3.8) determines the level of τ:

$$\tau_t = (r_t - 1)b + g \tag{1.9}$$

1.2.4 Environmental quality

It is supposed that production is a polluting activity. Both private and public maintenance can decrease the level of pollution, P_t.[12] The natural absorption rate is represented by η and represents the planet's capacity to reduce pollution without human intervention. The evolution of pollution thus follows:

$$P_{t+1} = (1 - \eta)P_t - \sigma m_t - \rho g_t + \beta y_t \tag{1.10}$$

12. Here, both private and public maintenance are considered as curative actions.

The maximum value of environmental quality is assumed to be $\tilde{e}$. It represents the *natural value* of the environment. This constant must be sufficiently high to ensure a positive environmental index [13] e_t which is defined as a deviation from $\tilde{e}$:

$$e_{t+1} = \tilde{e} - P_{t+1} \tag{1.11}$$

Substituting P_{t+1} by its expression leads to:

$$e_{t+1} = \tilde{e} - (1-\eta)P_t + \sigma m_t + \rho g_t - \beta y_t \tag{1.12}$$

Taking (1.11) in t and substituting P_t by its expression leads to:

$$e_{t+1} = \eta\tilde{e} + (1-\eta)e_t + \sigma m_t + \rho g_t - \beta y_t \tag{1.13}$$

where $\beta \in (0, \infty)$ represents the pollution that is associated with each unit of production. It should be noticed that a consumer born in t can only influence the environmental quality in $t+1$. Thus his/her life expectancy depends on choices made by previous generations.

1.3 Inter-temporal equilibrium

There are two assets in this economy: public bonds and capital. Equilibrium in the asset market is then defined by:

$$s_t = k_{t+1} + b \tag{1.14}$$

13. Numerous papers consider John & Pecchenino (1994)'s equation, which is nearly the same but without the constant $\eta\tilde{e}$. Here their approach is not convenient due to the use of a log-linear utility function. Using this index solves for that difficulty.

The standard maximization of utility with respect to m_t, c_t and d_{t+1} gives us the optimal choices of agents:

$$\begin{aligned} m_t^* &= \frac{(w_t-\tau_t)\pi(e_t)\gamma\sigma}{\sigma(1+\pi(e_t))} + \frac{[\eta\tilde{e}+(1-\eta)e_t+\rho g-\beta y_t][(\gamma-1)\pi(e_t)-1]}{\sigma(1+\pi(e_t))} && (1.15)\\ c_t^* &= \frac{w_t-\tau_t}{1+\pi(e_t)} + \frac{[\eta\tilde{e}+(1-\eta)e_t+\rho g-\beta y_t][(\gamma-1)\pi(e_t)-1]}{\pi\gamma\sigma(1+\pi(e_t))} \\ &\quad + \frac{\eta\tilde{e}+(1-\eta)e_t+\rho g-\beta y_t}{\pi\gamma\sigma} && (1.16)\\ s_t^* &= \frac{\pi(e_t)(1-\gamma)}{\sigma(1+\pi(e_t))}\left[(w_t-\tau_t)\sigma+\eta\tilde{e}+(1-\eta)e_t+\rho g-\beta y_y\right] && (1.17)\end{aligned}$$

Reintroducing (1.15) into the law of motion of the environment and (1.17) into (1.14), and then substituting for k_t, y_t, τ_t, r_t, and w_t by their corresponding expressions, the inter-temporal equilibrium may be defined.

Definition 1. *Given $e_0 \in (0,\infty)$ and $k_0 \in (0,\infty)$, an inter-temporal equilibrium is a sequence $(e_t, k_t) \in \mathbb{R}_+^* \times \mathbb{R}_+^*$ such that the following system is satisfied $\forall t \in (0;\infty)$:*

$$e_{t+1} = \frac{\pi(e_t)\gamma}{1+\pi(e_t)}\left[[(1-\epsilon)k_t^\epsilon - (\epsilon k_t^{\epsilon-1}-1)b-g]\sigma+\eta\tilde{e}+(1-\eta)e_t+\rho g-\beta k_t^\epsilon\right] \quad (1.18)$$

$$k_{t+1} = \frac{\pi(e_t)(1-\gamma)}{\sigma(1+\pi(e_t))}\left[[(1-\epsilon)k_t^\epsilon - (\epsilon k_t^{\epsilon-1}-1)b-g]\sigma+\eta\tilde{e}+(1-\eta)e_t+\rho g-\beta k_t^\epsilon\right]-b \quad (1.19)$$

Thus, the economy is driven by a dynamic system with two equations and two predetermined variables.

1.4 Steady states

In the following, it is assumed that:

$$\pi(e_{\mathrm{t}}) = \begin{cases} \bar{\pi} & if\ e_t \geq J \\ \underline{\pi} & if\ e_t < J \end{cases} \tag{1.20}$$

where $\bar{\pi} > \underline{\pi}$; $\underline{\pi}$ is not too low. When J is high, the probability that a country's households have a good life expectancy is lower. J can be interpreted as a variable capturing a type of technical level such as medical knowledge. Thus, a higher J may represent lower medical knowledge. In the model, we assume that J is a parameter given by nature. [14]

Definition 2. *A steady state is a couple $(e, k) \in (\mathbb{R}_+^* \times \mathbb{R}_+^*)$, such that the following equations are satisfied (here, when $e \geq J$):*

$$\begin{aligned} \theta(k) \quad &\equiv \quad e = \frac{\bar{\pi}\gamma}{1 + \bar{\pi} - \gamma\bar{\pi} + \gamma\eta\bar{\pi}} \\ &\times \quad \left[\sigma[(1-\epsilon)k^{\epsilon} - (\epsilon k^{\epsilon-1} - 1)b - g] + \eta\tilde{e} + \rho g - \beta k^{\epsilon}\right] \qquad (1.21) \\ \psi(e) \quad &\equiv \quad \frac{\bar{\pi}(1-\gamma)}{\sigma(1+\bar{\pi})}\left[\sigma(b-g) + \eta\tilde{e} + (1-\eta)e + \rho g\right] - b = k \\ &- \quad \frac{\bar{\pi}(1-\gamma)}{\sigma(1+\bar{\pi})}\left[\sigma[(1-\epsilon)k^{\epsilon} - \epsilon k^{\epsilon-1}b] - \beta k^{\epsilon}\right] = \phi(k) \qquad (1.22) \end{aligned}$$

Note the steady state in which $e < J$ is identical with $\underline{\pi}$ instead of $\bar{\pi}$. $\theta(k)$ is increasing and concave for $k \in (0, \infty)$ if $\beta < \sigma(1-\epsilon)$. If $\beta > \sigma(1-\epsilon)$, an inverse U-shaped relationship between environmental quality and the environment is obtained. For the sake of simplicity, this paper focuses on the increasing case:

Assumption 2: $\beta < \sigma(1-\epsilon)$

14. Here, life expectancy is considered as depending only on the environmental quality and J, as given by nature. A more realistic approach would endogenize life expectancy.

This choice is driven by empirical reasons. [15] While the increasing case represents a realistic situation for a set of pollutants (such as heavy particles, lead or nickel in rivers, and so on), the inverse U-shaped case is not realistic. [16] Assumption 2 thus allow to have $\theta(k)$ increasing for $k \in (0, \infty)$, from $\lim_{k\to 0}\theta(k) = -\infty$ to $\lim_{k\to\infty}(k) = +\infty$. Because $\lim_{k\to 0}\theta(k) = -\infty$, a condition restricting the space of k is needed. [17]

$\sigma[(1-\epsilon)k^{\epsilon} - (\epsilon k^{\epsilon-1} - 1)b - g] - \beta k^{\epsilon} \geq \boldsymbol{0}$

This condition implies the following: if the representative agent invests all his/her net income in private maintenance, he/she will be able to more than offset the emissions alone, without government intervention. Thus, this paper considers only $\{k_t\}$ such that $\theta(k_t) \geq 0$.

From (1.21) and (1.22), a steady state can be defined as a solution k solving $\Omega(k) \equiv \psi(\theta(k)) = \phi(k)$. $\psi(e)$ is always increasing with e from $\psi(-\infty) = -\infty$ to $\psi(+\infty) = +\infty$. Due to assumption 2, $\Omega(k)$ is increasing, from $\Omega(0) = -\infty$ to $\Omega(+\infty) = +\infty$.

$\phi''(k)$ is always positive between 0 and $+\infty$ in the case where $(1-\epsilon)\sigma \geq \beta$, which implies a convex function. A convex function indicates that the derivative $\phi'(k)$ is continuously increasing. Because $\lim_{k\to 0}\phi'(k) = -\infty$ and $\lim_{k\to+\infty}\phi'(k) = 1$, $\exists\, k^*$ such that $\phi'(k) < 0$ for $k > k^*$ and $\phi'(k) > 0$ for $k < k^*$.

When $\beta < \sigma(1-\epsilon)$, $\Omega(k)$ is continuously increasing. Thus there are two cases depending on the intercept. Assumption 2 implies that $\phi(k)$ is always positive for positive values of k. Moreover, even when $\phi(k)$ is negative for some values of k, the equilibrium should stay positive for a reasonable set of parameters.

There are two steady states for each level of π. $\beta < \sigma(1-\epsilon)$, so $\theta(k)$ is increasing with k. Consequently, there may be no conflict between environmental quality and capital accumula-

15. A thesis referee points out that an alternative law of motion for pollution such that $e_{t+1} = \tilde{e}^{\eta} e_t^{1-\eta} m_t^{\sigma} g_t^{\rho} y_t^{-\beta}$ allow to avoid this assumption. This function is close to equation (1.13) and allow for simplicity. If qualitative results are conserved using this formulation, such a function doesn't consider pollution as a stock.
16. For a deeper analysis of this point see Grossman & Krueger (1994).
17. It is notable that this condition is equivalent to $\sigma(w-\tau) \geq \beta k^{\epsilon}$.

tion. Indeed, the two equilibriums, (k_1, e_1) and (k_2, e_2), are characterized by $k_1 \leq k_2 \Leftrightarrow e_1 \leq e_2$.

1.5 Dynamics

As noted above, two steady states may coexist for each level of life expectancy. A phase diagram is used to analyze the dynamics. It provides a picture of convergence.

Using (1.18), $e_{t+1} \geq e_t \Leftrightarrow e_t \leq \theta(k_t)$. Thus, the locus $e_t = e_{t+1}$ describes an increasing and concave curve in the space (k_t, e_t). e_t is increasing below this curve and decreasing above it. Moreover, using (1.21), $\theta(k_t) = 0$ does not depend on the level of π. $\frac{\partial \theta(k_t)}{\partial \pi} > 0 \, \forall k_t, \theta(k_t) > 0$ implies that for a given k such that $\theta(k_t) > 0$, $\theta(k_t)_{\overline{\pi}} > \theta(k_t)_{\underline{\pi}}$. Using (1.19) $k_{t+1} \geq k_t \Leftrightarrow \psi(e_t) \geq \phi(k_t)$. $\psi(e_t)$ is increasing. Thus, $\psi(e_t) \geq \phi(k_t) \Leftrightarrow e \geq \psi \circ \phi(k_t) \equiv \Gamma(k_t)$. Because the focus is put on the case in which $\psi(e)$ is increasing, $e_t = \Gamma(k_t)$ is U-shaped. Indeed, $\phi(k_t)$ is U-shaped, and an increasing transformation of a U-shaped function is a U-shaped function. Above this curve, k_t is increasing, whereas k_t is decreasing below this curve. Moreover, $\Gamma(k_t)_{\underline{\pi}} > \Gamma(k_t)_{\overline{\pi}}$.

For each level of life expectancy, the low equilibrium is a saddle, while the high equilibrium is stable.

The dynamics are thus determined as in Figure 1.[18] Steady states correspond to the points where $\Gamma(k_t) = \theta(k_t)$.

The green curve prevails for a low life expectancy country, and the red curve prevails for a high life expectancy country. Plain lines represent those which prevail depending on the relative position of environmental quality and the J line. Obviously, the dynamics are widely affected by the choice of J. 5 types of dynamics may be determined depending on the level of J.

18. Depending on value of the parameters, the relative position of the curves may vary by a small amount. This potential variation does not change the conclusions of the present work.

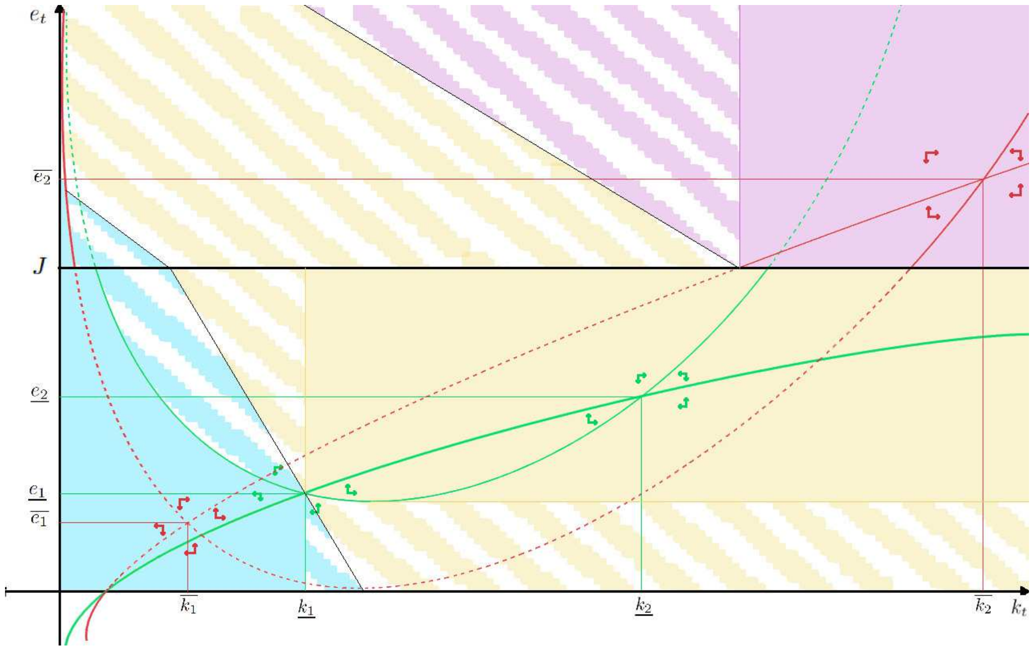

Figure 1.1 – The dynamics of the economy

In the following, $(\underline{k_1}, \underline{k_2}, \underline{e_1}, \underline{e_2})$ denote points for a low equilibrium and $(\overline{k_1}, \overline{k_2}, \overline{e_1}, \overline{e_2})$ denote points for a high equilibrium. [19]

Figure 1 represents the dynamics of the economy. Plain colorized surfaces are those with unconditional convergence. Hatched surfaces represent areas of convergence for which a curve has been arbitrarily chosen to characterize the dynamics. [20] When the trajectory crosses the J curve, there is no jump. The only effect it can have is a change in the speed of convergence (i.e., the slope of the curve). Therefore, this process allows the areas of convergence to be completely characterized.

On the whole, three types of areas that are characterized by different colors are observed. Each area represents the set of initial conditions such that the economy will converge towards

19. There may exist a wide range of phase diagrams depending on the relative position of the curves and the steady states and on the level of J. We decided to present one of the most interesting cases. All other cases are similar to this case or to the one presented in Appendix 2.

20. It was decided here arbitrarily to plot the path to see the dynamics. The arbitrary nature of the curve does not diminish the impact of the paper, because it is possible to obtain the actual curve as soon as the model is calibrated. But obtaining the curve is not the aim of the present work.

a positive stable steady state, or will fall into a trap. The blue area represents the set of initial conditions under which the economy will collapse and it is called the environmental poverty trap.[21] The yellow area represents the convergence towards an intermediate situation characterized by a low life expectancy, quite good environmental quality and an intermediate level of capital. The purple area represents the convergence towards the developed economies' equilibrium, which is characterized by a high level of capital, high environmental quality and high life expectancy. Figure 1 thus depicts the possibility that there are three groups of countries: developing, emerging and developed. The existence of the environmental poverty trap is consistent with the stylized fact presented by Mariani *et al.* (2010) on the bimodal distribution between life expectancy and the environment. In this model, exogenous *medical knowledge* is an important parameter. If an economy increases its *medical knowledge*, J decreases. A sufficient decrease in J ($J < \underline{e_2}$) implies that an economy initially in $(\underline{k_2}, \underline{e_2})$ will converge to the high steady state. However, this paper focuses on the preservation of the environment. Thus J is exogenously given by nature so that *mitigation* policies are banned.

A case where $\overline{e_1} > \underline{e_1}$ may also be obtained. This case does not cause problems since $(\overline{k_1}, \overline{e_1})$ only characterizes the occurrence of the trap. Finally, an economy with initial endowments in the blue area will collapse.

1.6 Comparative statics

This section studies how a government can use public expenditures and public debt to improve environmental quality, the level of capital, and in some cases, life expectancy. As previously mentioned, the low equilibrium is a saddle, and high equilibrium is stable. Then comparative statics around these two equilibriums need to be performed. That will show how the high equilibrium moves following a slight variation in b or g. Movement in the low equilibrium tells

21. The point $(\underline{k_1}; \underline{e_1})$ is a saddle. Thus, on the left of the saddle path, the economy will converge toward the point (0;0).

us whether variations in b or g make it harder or easier for the trap to emerge. This economy follows a public debt stabilization constraint: an increase in g means that the stabilization is done at a greater level of debt. The first differentiation of the system formed by (1.17) and (1.18) provides the following in matrix form:

$$\begin{bmatrix} O & P \\ Q & R \end{bmatrix} \begin{bmatrix} dk \\ de \end{bmatrix} = \begin{bmatrix} \pi\gamma\sigma(1-\epsilon k^{\epsilon-1}) & \gamma\pi(\rho-\sigma) \\ \frac{\sigma(1+\pi)}{\pi(1-\gamma)} - \sigma(1-\epsilon k^{\epsilon-1}) & \sigma-\rho \end{bmatrix} \begin{bmatrix} db \\ dg \end{bmatrix}$$

where

$$A = \begin{bmatrix} O & P \\ Q & R \end{bmatrix} = \begin{bmatrix} -\pi\gamma\sigma(1-\epsilon)\epsilon k^{\epsilon-1} - \pi\gamma\sigma(1-\epsilon)\epsilon b k^{\epsilon-2} + \pi\gamma\beta\epsilon k^{\epsilon-1} & 1+\pi-\pi\gamma+\gamma\eta\pi \\ -\frac{\sigma(1+\pi)}{\pi(1-\gamma)} + \sigma(1-\epsilon)\epsilon k^{\epsilon-1} + \sigma\epsilon b(1-\epsilon)k^{\epsilon-2} - \beta\epsilon k^{\epsilon-1} & 1-\eta \end{bmatrix}$$

The determinant of A, which is $OR - PQ$, can be written in the following form:

$$detA = (1+\pi-\gamma\pi+\gamma\eta\pi)\frac{\sigma(1+\pi)}{\pi(1-\gamma)}(\phi'(k) - \Omega'(k))$$

The determinant of A is thus negative at the low steady state, and it is positive at the high steady state. Then, the following equation may be used to analyze the impact of a small variation in g and b on k and e.

$$\begin{bmatrix} dk \\ de \end{bmatrix} = \frac{1}{\det A} \begin{bmatrix} R\pi\gamma\sigma(1-\epsilon k^{\epsilon-1}) + P\left(-\frac{\sigma(1+\pi)}{\pi(1-\gamma)} + \sigma(1-\epsilon k^{\epsilon-1})\right) & R\pi\gamma(\rho-\sigma) + P(\rho-\sigma) \\ -Q\pi\gamma\sigma(1-\epsilon k^{\epsilon-1}) + O\left(\frac{\sigma(1+\pi)}{\pi(1-\gamma)} - \sigma(1-\epsilon k^{\epsilon-1})\right) & Q\pi\gamma(\sigma-\rho) + O(\sigma-\rho) \end{bmatrix} \begin{bmatrix} db \\ dg \end{bmatrix}$$

Proposition 1. *The effects of a small increase in debt per capita b and public maintenance g on capital stock k and environmental quality e at the two steady states are summarized in Table 1.*

Proof. Proof is reported in appendix A.13. □

Proposition 1 reveals that a small increase in public debt can increase the level of environmental quality if the $\frac{b}{k}$ ratio is not too important. Moreover, a small increase in debt can limit the possibility that a developing country falls into the environment trap under the same condition. Nevertheless, public debt always has a negative impact on the level of capital at the stable

Table 1.1 – Comparative statics results

	db	dg
Low steady state		
dk_1	+	-
de_1	?*	-
High steady state		
dk_2	-	+
de_2	?*	+

* The sign depends on the $\frac{b}{k}$ ratio. The reader should refer to Appendix 3 for more details.

steady state because it implies an increase in taxes by the same order as equation (14), and it increases the probability that a developing country falls into the trap on the capital side. This last result appears to be consistent with the public debt literature. The underlying mechanisms are the following. An increase in public debt implies a crowding-out effect from private assets toward public bonds. Debt thus reduces the level of capital and production. The environmental quality may consequently increase due to lower externalities. Nevertheless, at some point, agents will finance the additional public debt by diminishing their maintenance. Thus, pollution will decrease on the production side but will increase overall because of less maintenance. It should be noted that since the steady state is studied, public debt is not a means of financing public maintenance. It will only increase taxes.

According to proposition 1, an increase in public expenditure to maintain the environment always has a positive impact on the economy. For a developed economy, this investment increases both environmental quality and the level of capital due to assumption 1. An increase in public maintenance financed by taxes frees more resources to the household for capital accumulation for a given level of environmental quality. At a given level of capital, the government can take all the resources initially devoted to private maintenance to finance public maintenance, which is more efficient. The effect on environmental quality will thus be positive.

At this stage, the comparative statics allow some comparisons to be made with environmental policies. A country that aims to improve both environmental quality and growth in a context of a high level of public debt should opt for a debt reduction and an increase in public expenditure, in the spirit of debt-for-nature swaps, a mechanism that may be used by developing countries to finance an environmental policy. This consists in the following: a conservation organization (rarely a national government) may buy a part of a country's debt at a discounted price in the secondary debt market and this debt is then canceled if the debtor takes some environmental protection measures.

An interesting effect occurs when one takes the case in which three equilibriums may exist. A sufficiently large increase in environmental maintenance or public debt can increase the environmental level of the intermediate equilibrium (emerging economy) such that the economy will cross the J frontier and thus converge finally on the developed economies' equilibrium. But such a policy needs to be well calibrated. An increase in g may always help to cross the J threshold, but an increase in b should be used only as long as the debt ratio is sufficiently low. Indeed, proposition 1 establishes that there is a maximum value of the debt ratio, such that environmental quality is positively affected by an increase in public debt.

As noted in the previous section, a progress in medical knowledge may also help an economy to reach the high steady state, mitigating the adverse effects of pollution on life expectancy. Higher life expectancy will increase households' incentives to invest both in capital and in the preservation of environmental quality.

1.7 Welfare analysis

This section analyzes the capacity of a policy based on public debt leading to the optimal allocation. The focus is only put on the stationary path. That section follows De La Croix & Michel (2002) by considering that g is a given constant. It is shown that for an appropriate choice of the public debt level, the optimal equilibrium may be decentralized. The social planner faces two constraints. Production at each date may equalize the consumption of young and old households, savings, private maintenance and public expenditures. Savings may be considered directly since $N = 1$ for each date. Substituting savings by equation (1.14), the budgetary constraint of the social planner is:

$$\xi(k) - g = c + m + \pi d \tag{1.23}$$

where $\xi(k) = k^\epsilon - k$. This is a concave function and $\xi'(k) > 0\,(< 0)$ for $k < \tilde{k}\,(k > \tilde{k})$ where $\tilde{k} = \epsilon^{\frac{1}{1-\epsilon}}$. An optimal allocation needs $\xi(k) \geq g$. $\xi(\tilde{k}) = \epsilon^{\frac{\epsilon}{1-\epsilon}}(1-\epsilon)$. For $g < \xi(\tilde{k})$, there exist two solutions $\underline{k}$ and $\overline{k}$ satisfying $\xi(k) = g$. It implies that a stationary optimal allocation $\hat{k}$ is characterized by $\hat{k} \in (\underline{k}, \overline{k})$. The social planner also faces an environmental constraint:

$$e = \tilde{e} + \frac{\sigma m + \rho g - \beta k^\epsilon}{\eta} \tag{1.24}$$

Using (1.23) and (1.24), we can express c as:

$$c = k^\epsilon - k - g - \pi d - \frac{1}{\sigma}\left[\eta e + \eta \tilde{e} + \rho g - \beta k^\epsilon\right] \tag{1.25}$$

The utility function of the central planner is:

$$U(c, e, d) = \ln(c) + \pi\gamma \ln(e) + \pi(1-\gamma)\ln(d) \tag{1.26}$$

Substituting (1.25) in the utility function, the central planner maximizes (1.26) with respect to k, e, and d. The optimal steady state is then characterized by:

$$\hat{k} = \left[\frac{\epsilon(\sigma-\beta)}{\sigma}\right]^{\frac{1}{1-\epsilon}} \tag{1.27}$$

$$\hat{e} = \frac{\pi\gamma}{\eta(1+\pi)}\left[(\sigma-\beta)\left[\frac{\epsilon(\sigma-\beta)}{\sigma}\right]^{\frac{\epsilon}{1-\epsilon}} - \sigma\left[\frac{\epsilon(\sigma-\beta)}{\sigma}\right]^{\frac{1}{1-\epsilon}} + (\rho-\sigma)g + \eta\tilde{e}\right] \tag{1.28}$$

Here, an environmentally modified golden rule is first obtained. Indeed, the first expression is the Samuelson golden-rule level of capital multiplied by an environmental factor.[22] This can be seen quite easily assuming that $\beta = 0$ such that there are no environmental damages linked with production. Indeed, if $\beta = 0$ the Samuelson golden rule is obtained.[23] Then some recommendations for economic policy can be provided. Equation (1.28) is a function of g.[24] It allows the level of public expenditure $g(\hat{e})$ to be obtained that is necessary to reach a realistic environmental target $\hat{e}$.[25] Using (1.21) and (1.22), the optimal equilibrium may be decentralized using debt. If the economy is over-accumulating capital, an increase in public debt may be useful to reach the steady state. Agents will substitute debt for capital in their saving plans. This allows k to be reduced to the golden rule level. If the economy is under-accumulating, a debt reduction which implies a lower taxation rate at the steady state frees up some resources for household savings. Depending on the environmental target, the government can also increase taxes to finance higher public maintenance. If the economy was initially characterized by the golden rule level, this tax increase may be compensated by a decrease in the public debt which reduces taxes at the steady state.

1.8 Conclusion

In this paper, a simple model is used to obtain a representation of the world with three groups of countries. As all variables are backward looking, the dynamics followed by countries and the steady state reached depend on nature and initial endowments. This deterministic framework leaves some room for political intervention. Unlike Fodha & Seegmuller (2014), this article does not depict a conflict between life expectancy and the environment. Policy rec-

22. See Samuelson (1958).
23. We obtain directly the Samuelson golden rule for $\sigma \neq 0$. For $\sigma = 0$, the model could be rewritten without private maintenance and we also find the Samuelson golden rule.
24. Reintroducing this equation in (1.26), using equations (1.25) and (1.27), and maximizing with respect to g may allow to find the optimal level of public maintenance.
25. It should be remembered that $g < \epsilon^{\frac{\epsilon}{1-\epsilon}}(1-\epsilon)$.

ommendations are thus follow from a model closer to the preexisting literature. A voluntary environmental policy may be able to keep a country out of the environmental poverty trap and also enable emerging economies to reach a better stage of development. Indeed, it affects positively both the environmental quality and the level of development. It may also increase life expectancy. While public debt must be used very cautiously, this paper shows that it is nevertheless a useful tool. It always has a negative effect on the level of capital, through a crowding-out effect on private spending. Its effect on the environmental quality is positive below some level of the debt ratio. If this ratio is exceeded, its effect becomes negative. A positive level of public debt may help an economy that over-accumulates capital to reach optimality. In addition, this paper argues for debt-for-nature swap mechanisms in certain situations.

Further studies may consider a distortive tax or a non-constant level of debt. These should allow the use of debt to finance public maintenance, which may have a positive effect on both capital and environmental quality. The dynamic adjustment of a shock in public debt should be more interesting in such a framework, but it will probably allow for complex dynamics. It may also be interesting to endogenize the life expectancy parameter. In the real world, we can reasonably assume that life expectancy depends essentially on the quality of the environment, the level of human capital, and the income level, in this order. Part of this phenomenon is captured through the environmental threshold, but this type of modelization is not a first best.

Appendices

A.11 Stylized fact: A negative correlation between public debt and the environmental quality

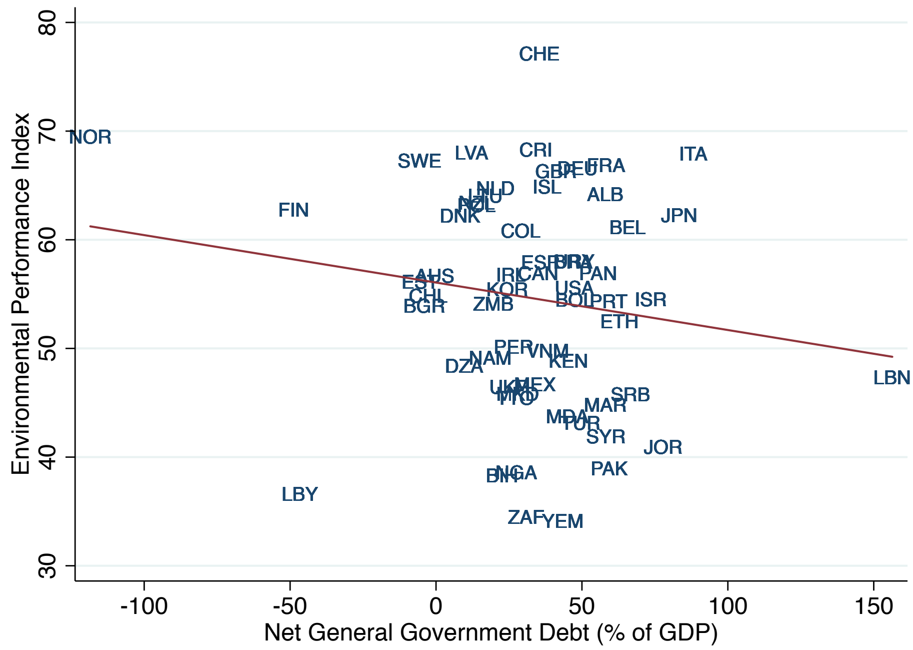

Figure 2 – Correlation between Net General Government Debt and the EPI

The correlation coefficient between the mean of the Net General Government Debt ratio and the mean of the EPI over the 2000-2010 period is -0.161. It is significant at the 1 percent level.

The correlation is performed on a sample of 59 countries (see Table 2).

Table 2 – List of countries (2000-2010)

Albania	Algeria	Australia	Belgium
Bolivia	Bosnia and Herzegovina	Brazil	Bulgaria
Canada	Chile	Colombia	Costa Rica
Denmark	Estonia	Ethiopia	Macedonia
Finland	France	Germany	Iceland
Ireland	Israel	Italy	Japan
Jordan	Kenya	South Korea	Latvia
Lebanon	Libya	Lithuania	Mexico
Moldova	Morocco	Namibia	Netherlands
New Zealand	Nigeria	Norway	Pakistan
Panama	Peru	Poland	Portugal
Serbia	South Africa	Spain	Sweden
Switzerland	Syria	Trinidad and Tobago	Turkey
Ukraine	United Kingdom	United States of America	Uruguay
Viet Nam	Yemen	Zambia	

The EPI data come from the Yale Center for Environmental Law and Policy Hsu *et al.* (2014). The Net General Government Debt data come from the World Economic Outlook database (IMF, 2014).

A.12 Another exemple of Dynamics

As explained in Section 5, the present phase diagram is one of a wide range of possibilities. Indeed, our relative steady states may vary a little given the position of the curves. In fact, $\overline{e}_1$ may be higher than $\underline{e_2}$. That possibility does not change the policy recommendation because these points only represent the environmental trap's situation. It may only improve or reduce the probability of falling into the trap when we give values are given to parameters.

Depending on where the J threshold is placed, the dynamics may vary somewhat. Section 5 presents the case in which there are three areas of convergence. If we decided to improve medical knowledge (i.e., impose a lower J), there are thus have two convergence areas. Indeed, the point $(\underline{k_2}, \underline{e_2})$ is no longer an attraction point because $\underline{e_2}$>J. The convergence area toward the high equilibrium is thus larger. This is represented in Figure 3.

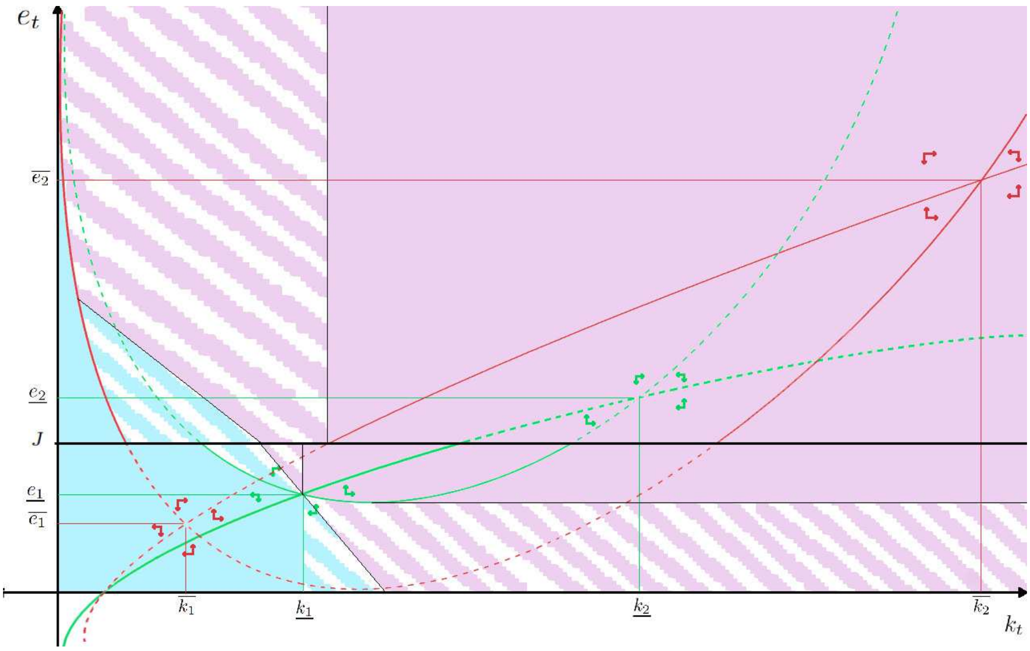

Figure 3 – Dynamics when $\underline{e_1} \leq J \leq \underline{e_2}$

It is also possible to look at the extreme case. If medical knowledge is very high, $J < \overline{e_1}$, the curves that prevail for the analysis of dynamics are in red. If medical knowledge is very low, $J > \overline{e_2}$, the curves that prevail are in green. Nevertheless, failing to present an exhaustive list of phase diagrams does not diminish the paper because the policy implications are the same in all cases.

A.13 Proof of proposition 1

Variation of dk with respect to db

$$
\begin{aligned}
R\pi\gamma\sigma(1-\epsilon k^{\epsilon-1}) - P\left[\frac{\sigma(1+\pi)}{\pi(1-\gamma)} - \sigma + \sigma\epsilon k^{\epsilon-1}\right] \\
&= (1-\eta)\pi\gamma\sigma(1-\epsilon k^{\epsilon-1}) - (1+\pi+\pi\gamma\eta-\pi\gamma)\left[\frac{\sigma(1+\pi)}{\pi(1-\gamma)} - \sigma + \sigma\epsilon k^{\epsilon-1}\right] \\
&= (1+\pi)\sigma(1-\epsilon k^{\epsilon-1}) - (1+\pi+\pi\gamma\eta-\pi\gamma)\frac{\sigma(1+\pi)}{\pi(1-\gamma)}
\end{aligned}
$$

This is higher than zero for $k \leq \frac{-1-\pi\gamma\eta}{\pi(1-\gamma)\epsilon} < 0$, which is impossible. This expression is thus always negative. Given the sign of the determinant, we obtain the signs that we put in the corresponding cases in Table 1.

Variation of dk with respect to dg

$$
\begin{aligned}
R\pi\gamma(\rho-\sigma) + P(\rho-\sigma) &= (1-\eta)\pi\gamma(\rho-\sigma) + (1+\pi+\pi\gamma\eta-\pi\gamma)(\rho-\sigma) \\
&= (1+\pi)(\rho-\sigma)
\end{aligned}
$$

Given assumption 1, this is always positive. Given the sign of the determinant, the signs that are put in the corresponding cases in Table 1 are obtained.

Variation of de with respect to db

$$
\begin{aligned}
& -Q\pi\gamma\sigma(1-\epsilon k^{\epsilon-1}) + O\left(\frac{\sigma(1+\pi)}{\pi(1-\gamma)} - \sigma(1-\epsilon k^{\epsilon-1})\right) \\
= \; & \pi\gamma\sigma(1-\epsilon k^{\epsilon-1}) \times \left[\frac{\sigma(1+\pi)}{\pi(1-\gamma)} - \sigma(1-\epsilon)\epsilon k^{\epsilon-1} - \sigma\epsilon(1-\epsilon)bk^{\epsilon-2} + \beta\epsilon k^{\epsilon-1}\right] \\
& + \left[\frac{\sigma(1+\pi)}{\pi(1-\gamma)} - \sigma(1-\epsilon k^{\epsilon-1})\right] \times \left[-\pi\gamma\sigma(1-\epsilon)\epsilon k^{\epsilon-1} - \pi\gamma\sigma(1-\epsilon)\epsilon bk^{\epsilon-2} + \pi\gamma\beta\epsilon k^{\epsilon-1}\right] \\
= \; & +\frac{\sigma(1+\pi)}{\pi(1-\gamma)}\left[\sigma\pi\gamma(1-\epsilon k^{\epsilon-1}) - \pi\gamma\sigma(1-\epsilon)\epsilon k^{\epsilon-1} - \pi\gamma\sigma(1-\epsilon)\epsilon bk^{\epsilon-2} + \pi\gamma\beta\epsilon k^{\epsilon-1}\right]
\end{aligned}
$$

This is higher than 0 if:

$$
\begin{aligned}
\sigma - \sigma\epsilon k^{\epsilon-1} - \sigma(1-\epsilon)\epsilon k^{\epsilon-1} - \sigma(1-\epsilon)\epsilon bk^{\epsilon-2} + \beta\epsilon k^{\epsilon-1} &> 0 \\
\sigma k^{1-\epsilon} - 2\sigma\epsilon + \sigma\epsilon^2 - \sigma\epsilon\frac{b}{k} + \sigma\epsilon^2\frac{b}{k} + \beta\epsilon &> 0
\end{aligned}
$$

Thus, it can easily be confirmed that the sign will crucially depend on the $\frac{b}{k}$ level.

Variation of de with respect to dg

$$
\begin{aligned}
Q\pi\gamma(\sigma-\rho) + O(\sigma-\rho) &= \pi\gamma(\sigma-\rho)\left[\sigma(1-\epsilon)\epsilon k^{\epsilon-1} + \sigma\epsilon k^{\epsilon-2}(1-\epsilon)b - \frac{\sigma(1+\pi)}{\pi(1-\gamma)} - \beta\epsilon k^{\epsilon-1}\right] \\
&\quad +(\sigma-\rho)\left[\pi\gamma\epsilon\beta k^{\epsilon-1} - \pi\gamma(1-\epsilon)\epsilon b\sigma k^{\epsilon-1} - \pi\gamma\sigma(1-\epsilon)\epsilon k^{\epsilon-1}\right] \\
&= -\frac{\sigma(1+\pi)\pi\gamma(\sigma-\rho)}{\pi(1-\gamma)} \\
&= \frac{\sigma(1+\pi)\gamma(\rho-\sigma)}{1-\gamma}
\end{aligned}
$$

Given assumption 1, this is always positive. Given the sign of the determinant, the signs are obtained that are put in the corresponding cases in Table 1.

Chapitre 2

Growth in an Overlapping Economy with a Polluting Non-Renewable Resource

2.1 Introduction

Since the 70's, one of the most discussed question among economists is essentially: "Can economies endowed with a finite stock of an essential non-renewable resource may grow indefinitely ?". If the Club of Rome's answer was pessimistic, this view has been challenged by neoclassical economists. Notably, Stiglitz (1974), Solow (1974), Dasgupta & Heal (1974, 1979) have highlighted the importance of (exogenous) technical progress, increasing returns and substitution possibilities between man-made and natural capital in order to surpass the problem of resource depletion.

Those authors use the infinitely-lived agents (ILA) framework. This choice is not without consequences. In ILA models, agents are implicitly assumed to be intergenerationally altruistic. More precisely, the ILA framework assumes a dynastic altruism where parents are able to maximize the welfare of their children. If such an altruism is not supported by empirical results

(Altonji *et al.* (1992)), there also exist other types of altruism. The paternalist altruism represents a biased altruism: [1] agents take care of some constituents of their children consumption, not equated with their children welfare, but with believes on what is good for them (McConnell, 1997; Lazo *et al.* , 1997). In any case altruism tends to make a sustainable management more probable: since current generations take care of future ones, they are more likely to preserve the resource stock or to invest the rent in order to promote a decent standard of living for future generations following the Hartwick's rule.

This observation has led to the work of Agnani *et al.* (2005). Those authors use the overlapping generation (OLG) framework, in which each generation is supposed to be perfectly selfish, to study the sustainability of growth with natural resources. In an OLG framework, agents are prone to consume a larger share of the natural rent than in the ILA framework: the economy is more likely to contract. [2] Formally, Agnani *et al.* (2005) show that the labor share has to be large enough to allow for a positive balanced growth rate. A high labor share allows savings to compensate for resource depletion and makes the economy sustainable. If the labor share is not high enough the economy will contract.

One important feature of natural resources neglected by Agnani *et al.* (2005) is the pollution resulting from their extraction or use in the production process. Indeed, many real world environmental problems come from natural resources: resource extraction is a polluting activity, especially for metals (gold, silver, nickel...), while it is the resource use in production which is polluting for other non-renewable resources (oil, coal...). Thus, we will introduce an environmental externality in their model in order to analyze the impact of a pollution resulting from natural resources on the economy. If there exist numerous paper highlighting that human activities are sources of pollution, this pollution is often modeled as a stock increasing with

1. This form of altruism seems empirically supported (see for example Jacobsson *et al.* (2007) or Rodríguez & León (2004))

2. If one cannot infer that agents are selfish, using OLG model without altruism in order to study sustainability issues allows to obtain strong results: the introduction of altruism in the model should relax constraints on sustainability.

total output (Jouvet *et al.* , 2010), consumption (John & Pecchenino, 1994), or capital stock (Gradus & Smulders, 1993). In opposition, few papers have introduced pollution as resulting from resource extraction and/or resource use in the production process. Notable exception are Babu *et al.* (1997) and Schou (2000, 2002).[3] While the literature usually concentrates on stock pollutants, we will introduce pollution as a flow affecting current factor productivity. This simplifying assumption shouldn't be shown as restrictive. Indeed, there exists numerous pollutants with short lifetime (sulphur, black carbon, fine air particulate, nitrogen dioxide, tropospheric ozone...) which may be considered as flow pollutants, especially in the OLG framework where a period accounts for 25-30 years. Those pollutants are known to have effects on health (and thus worker productivity), land productivity, and may affect negatively plants (through acid rain for example). Flow emissions are often associated with stock emissions. Nevertheless the impact of flow emissions on the economy has known little attention from economists while they can lead to interesting results. In this framework, it will be shown that the existence of a pollution resulting from natural resources enhances the ability of the economy to sustain a non-decreasing consumption path. More precisely, the more the pollution affects factor productivity, the less the resource will be used in the production, releasing the level of investment necessary to compensate for resource depletion.[4]

This work also analyzes the impact of resource dependence on sustainability. Not surprisingly, a resource dependent economy is less likely to exhibit positive long-run growth, because it needs more savings for capital accumulation to compensate for a faster resource depletion.

Finally, the last contribution of the chapter is to surpass the Pareto efficiency criterion used by Agnani *et al.* (2005). While in the ILA framework decentralization of the Ramsey allocation does not require public intervention because the flow pollution is not distortive (Schou, 2000),

3. We focus here on general equilibrium literature. There also exists a deep literature that focuses on the exhaustible-resource/pollution problem (see for example Withagen, 1994).

4. In the very long run and abstracting from emission ceiling, this results stay true with stock pollutants: emissions are caused by a natural resource which tends to be exhausted so that emissions tends to zero and the natural absorption prevents the stock of pollutant to grow.

this is not ever true in the OLG framework: the discrete time formulation with finite lifetime exhibits limitation of the market. Indeed, in presence of rational selfish agents, the market is not able to preserve the welfare of unborn generations. We thus propose two alternative instruments which may be used in order to decentralize a Ramsey optimal equilibrium. If the economy follows the usual assumption that the resource initially belongs to the first generation of agents, the Ramsey optimal equilibrium may be decentralized using a tax which is characterized. If we assumes that the resource is shared by all generations of agents, we are able to characterize the optimal policy that should be followed by an independent trust fund.

The rest of the paper is organized as follow: section 2 presents the decentralize economy, section 3 develops the Ramsey economy, section 4 is devoted to the decentralization of the Ramsey optimal allocation while section 5 concludes.

2.2 The decentralized economy

2.2.1 The Model

We use the two-period OLG model with one representative good. Agents are alive for two periods. For the sake of simplicity, no demographical growth is assumed and the size of the working force is normalized to one. [5]

The Non-Renewable Resource

Following Agnani *et al.* (2005) the economy is initially endowed with a quantity m_{-1} of a necessary exhaustible resource held by the first generation of aged agents. At each date t, elderly agents sell their resource share to the young generation and a quantity x_t of the resource

5. Lowercases represent per worker variables.

is used in the production process and generates an environmental externality. The resource stock in t is thus denoted by $m_t = m_{t-1} - x_t$ and it belongs to the generation t. The rate of exhaustion of the natural asset is:

$$q_t = \frac{x_t}{m_{t-1}} \tag{2.1}$$

The dynamics of the per worker resource stock is thus [6]:

$$m_t = (1 - q_t)m_{t-1} \tag{2.2}$$

It leads, associated with the non renewability of the resource, to the exhaustibility condition

$$1 \geq \sum_{t=0}^{\infty} q_t \prod_{j=1}^{t} (1 - q_{j-1}) \tag{2.3}$$

Consumers

As in Agnani *et al.* (2005), agents are alive for two periods and maximize the following utility function:

$$u_t(c_t; d_{t+1}) = ln(c_t) + \frac{1}{1+\rho} ln(d_{t+1}) \tag{2.4}$$

where c represents the consumption while young, d the consumption while old and ρ the individual rate of time preference.

In the first period of life, the representative agent works to earn a wage w_t, which may be consumed, saved as physical capital s_t, or used to buy rights on the resource stock m_t at a price p_t in terms of the representative good. His first period budget constraint is:

$$w_t = c_t + s_t + p_t m_t \tag{2.5}$$

While old, he gets his savings increased at the interest rate, and he sells his resource rights at a

6. It may also be interpreted as a resource market clearing condition as in Agnani *et al.* (2005).

price p_{t+1}. His second period budget constraint is

$$d_{t+1} = (1 + r_{t+1})s_t + p_{t+1}m_t \tag{2.6}$$

Combining 2.5 and 2.6, we obtain the following inter-temporal budget constraint (IBC hereafter):

$$w_t = c_t + \frac{d_{t+1}}{1 + r_{t+1}} - \frac{p_{t+1}m_t}{1 + r_{t+1}} + p_t m_t \tag{2.7}$$

The maximization of utility with respect to m_t, c_t, d_{t+1} subject to the IBC leads to the following first order conditions:

$$\frac{d_{t+1}}{c_t} = \frac{1 + r_{t+1}}{1 + \rho} \tag{2.8}$$

$$\frac{p_{t+1}}{p_t} = 1 + r_{t+1} \tag{2.9}$$

(2.8) is the standard Euler equation while (2.9) is an arbitrage condition between the two assets in this economy, capital and resource.

Firms

Firms produce the representative good Y_t using a Cobb-Douglas technology. They use capital K_t, labor N_t, and resources X_t, with constant returns to scale for a given level of technology A_t which grows at a rate a such that:

$$A_{t+1} = (1 + a)A_t \tag{2.10}$$

The extraction and use of the resource in the production process generate a flow of pollution e_t such that:

$$e_t = \phi x_t \tag{2.11}$$

Pollution resulting from the use of the resource in the production process generates a productivity loss. The flow pollution considered here is not so reductive. There exists a wide variety of pollutant with short lifetime that may cause productivity losses. For example sulfur dioxide resulting from the burning of fossil fuel is a major cause of acid rain. Tropospheric ozone resulting from fossil fuel burning [7] generates health issues that may affect directly the productivity of workers (Zivin & Neidell, 2012) [8]. θ captures the detrimental impact of pollution on the level of production. Nielsen *et al.* (1995) and Schou (2000) model the detrimental effect from pollution on productivity in the same way. The production function is thus:

$$y_t = A_t k_t^{\alpha} x_t^{v} e_t^{-\theta} \tag{2.12}$$

with $\alpha + \beta + v = 1$. [9] Thus, the model assumes constant return to scale from the firm point of view. Indeed, the environmental externality is not taken into account by individual firms but they consider the aggregated level of pollution as given while they decide their production plan.

Capital is remunerated at the interest rate r_t and depreciates at a rate $0 < \delta < 1$. Firms pay a wage w_t to their workers and buy the natural input at its price p_t. The profit of the representative firm is thus:

$$\Pi_t = A_t k_t^{\alpha} x_t^{v} e_t^{-\theta} - (r_t + \delta) k_t - w_t - p_t x_t \tag{2.13}$$

We focus on the case $\theta < v$. That is, for an identical amount of resource and emissions, we assume that the positive impact of resources on income outweighs its negative one. A similar assumption may be found in Schou (2000), where pollution is also seen as a flow. The standard

7. More precisely, ozone is produced through the interaction of nitrogen dioxide with dioxygen and sun.

8. An effect of pollution on health also affects agents utility and would be better modeled if also introduced in the utility function. For the sake of simplicity, we do not consider the impact of pollution on utility which could be analyzed in future research.

9. β represents the elasticity of production with respect to labor which is normalized to one.

profits maximization leads to the following first order conditions:

$$r_t = \alpha A_t k_t^{\alpha-1} x_t^v e_t^{-\theta} - \delta \tag{2.14}$$

$$w_t = \beta A_t k_t^{\alpha} x_t^v e_t^{-\theta} \tag{2.15}$$

$$p_t = v A_t k_t^{\alpha} x_t^{v-1} e_t^{-\theta} \tag{2.16}$$

Each factor is thus paid at its marginal productivity. [10]

2.2.2 The Balanced Growth Path

The economy produces a representative good which may be consumed or saved as physical capital. Following Diamond (1965), the good market clearing condition is

$$s_t = k_{t+1} \tag{2.17}$$

Definition 3. *An inter-temporal competitive equilibrium is a solution of the system formed by the following equations:*

$$\beta(1+a)^t A_0 k_t (m_{t-1} - m_t)^{v-\theta} \phi^{-\theta} = (2+\rho)[k_{t+1} + v(1+a)^t A_0 k_t^{\alpha} (m_{t-1} - m_t)^{v-1-\theta} \phi^{-\theta} m_t] \tag{2.18}$$

$$(1+a)\frac{k_{t+1}^{\alpha}(m_t - m_{t+1})^{v-1-\theta}}{k_t^{\alpha}(m_{t-1} - m_t)^{v-1-\theta}} = 1 + \alpha(1+a)^{t+1} A_0 k_{t+1}^{\alpha-1} (m_t - m_{t+1})^{v-\theta} \phi^{-\theta} - \delta \tag{2.19}$$

This system is a system of second order equations. Assuming a constant extraction rate q,

10. This paper concentrates on interior solutions.

the system may be rewritten in terms of first order equations:

$$\beta(1+a)^t A_0 k_t x_t^{v-\theta}\phi^{-\theta} = (2+\rho)[k_{t+1} + v(1+a)^t A_0 k_t^{\alpha} x_t^{v-1-\theta}\phi^{-\theta} x_{t+1}/q] \tag{2.20}$$

$$(1+a)\frac{k_{t+1}^{\alpha} x_{t+1}^{v-1-\theta}}{k_t^{\alpha} x_t^{v-1-\theta}} = 1 + \alpha(1+a)^{t+1} A_0 k_{t+1}^{\alpha-1} x_{t+1}^{v-\theta}\phi^{-\theta} - \delta \tag{2.21}$$

Then, remarking that p_0 is a jump variable which is not given by history, we can assume that p_0 jumps instantaneously to a value that ensures a constant extraction path.

The rest of the paper focuses on balanced growth path because they constitute the only case where long-run positive growth is possible, as noted in Agnani *et al.* (2005). Moreover, it is in accordance with stylized facts of growth literature.

Definition 4. *An inter-temporal equilibrium where all variables grow at a constant rate is defined as a balanced growth path (BGP hereafter).*

Let μ_h be the BGP notation of the ratio h_{t+1}/h_t. According to definition 4, μ_m should be constant. Thus (2.2) implies a constant rate of extraction along the BGP, i.e. $q_t = q_{t+1} = q$.

Proposition 2. *This overlapping economy is characterized by the following growth rates:*

$$\begin{aligned}
\mu_k &= \mu_y = \mu_s = \mu_w = \mu_c = \mu \\
\mu_x &= \mu_e = \mu_m = 1 - q \\
\mu_p &= \mu/\mu_x \\
\mu_a &= 1 + a \\
\mu_r &= 1 \\
\mu &= (1+a)^{\frac{1}{1-\alpha}}(1-q)^{\frac{v-\theta}{1-\alpha}}
\end{aligned}$$

Proof. Proof is reported in appendix A.21 . □

From Proposition 2, it may be established that a necessary condition for a long run positive growth is $q < 1 - (1+a)^{\frac{1}{\theta - v}}$. This threshold will be referred as a positive growth threshold (PGT hereafter). To analyze how the balanced growth path is affected by a change in θ, it is necessary to characterize the constant extraction rate. The market clearing condition (2.17) may be written, using (2.5), (2.6), (2.8), (2.15), (2.16), as:

$$k_{t+1} = \left[\frac{\beta}{2+\rho} - \frac{(1-q)v}{q}\right] A_t k_t^{\alpha} x_t^{v} e_t^{-\theta} \tag{2.22}$$

Evaluating this equation at the BGP, we can obtain:

$$\frac{(1+a)^{\frac{1}{1-\alpha}}(1-q)^{\frac{v-\theta}{1-\alpha}}\alpha(2+\rho)q}{\beta q - v(1-q)(2+\rho)} = \frac{(1+a)^{\frac{1}{1-\alpha}}(1-q)^{\frac{v-\theta}{1-\alpha}}}{1-q} - (1-\delta) \tag{2.23}$$

It may now be established that q^* is solution to the preceding non linear equation. We denote LHS and RHS the left and right hand side of (2.23). $RHS(q)$ is defined on $[0;1[$ with $RHS(0) = (1+a)^{\frac{1}{1-\alpha}} - (1-\delta)$. Since $\lim_{q\to 1} RHS(q) = +\infty$, $RHS(q)$ admits a vertical asymptote in $q = 1$. Moreover, $\frac{\partial RHS(q)}{\partial q} > 0$ and $\frac{\partial RHS(q)^2}{\partial^2 q} > 0$ imply an increasing and convex function. $LHS(q)$ is defined on $[0;\hat{q}[\,U\,]\hat{q};1]$ with $\hat{q} = \frac{v(2+\rho)}{\beta + v(2+\rho)}$. $LHS(q) < 0\,\forall\, q < \hat{q}$ which do not allow the possibility of an equilibrium extraction rate given that $RHS(q) > 0\,\forall\, q \in [0;1[$. Since $lim_{q\to\hat{q}_{(+)}} = +\infty$ and $lim_{q\to 1} = 0$ it exists a unique q^* such that (2.23) is satisfied. This situation is represented in Figure 2.1.

The threshold $\hat{q}$ is called the growth area threshold (GAT hereafter). Indeed, an increase in the GAT reduces the set of q such that the economy grows at the BGP, because the economy contracts if $PGT < \hat{q}$.

From Proposition 2 it appears that an higher extraction rate is associated with a lower growth while looking at (2.1) and (2.12), an increase in q implies an higher income. It is thus necessary to distinguish between short and long run impacts of a higher extraction rate. In the short run, an increase in q, *ceteris paribus*, implies an increase of one input in the production process. Current production thus increases. Nevertheless, it will be harder to maintain this level of

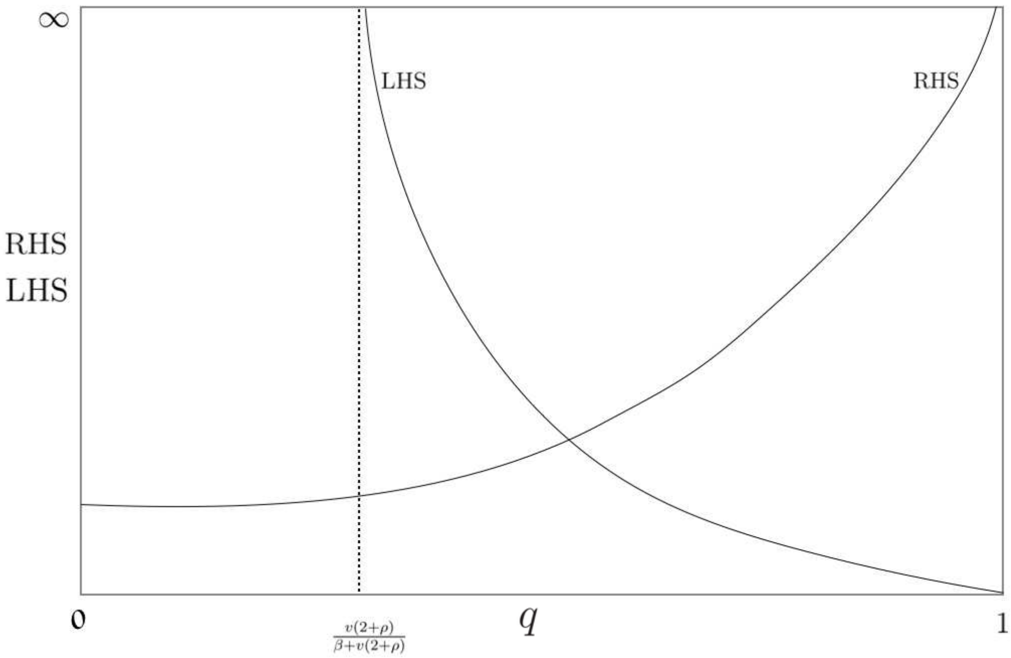

Figure 2.1 – Characterization of the competitive equilibrium extraction rate

production, because less natural resources are available to produce. In the long run, the higher is the extraction, the more the economy needs capital to compensates for resource depletion. The pressure on natural resources thus limits future growth possibilities.

2.2.3 The impact of flow pollution on sustainability

In this work, we define sustainability as the ability of the economy to sustain a non-declining balanced consumption path. The economy will contract if $PGT < GAT$ *i.e.* if $\beta < \frac{(1+a)^{\frac{1}{\theta-v}}(2+\rho)v}{1-(1+a)^{\frac{1}{\theta-v}}}$. This condition is less likely to be satisfied when θ increases. Figure 2.2 represents the results of a numerical simulation in order to see how the sustainability of the economy is affected when θ increases, keeping the constant returns to scale assumption. The simulation is performed for the following annual values: $a = 0.028$, $\delta = 0.027$, $\rho = 0.016$.[11] The space over the curve

11. The choice of parameter values comes from Agnani *et al.* (2005).

represents the set of capital, resource and labor shares such that the economy will contract.

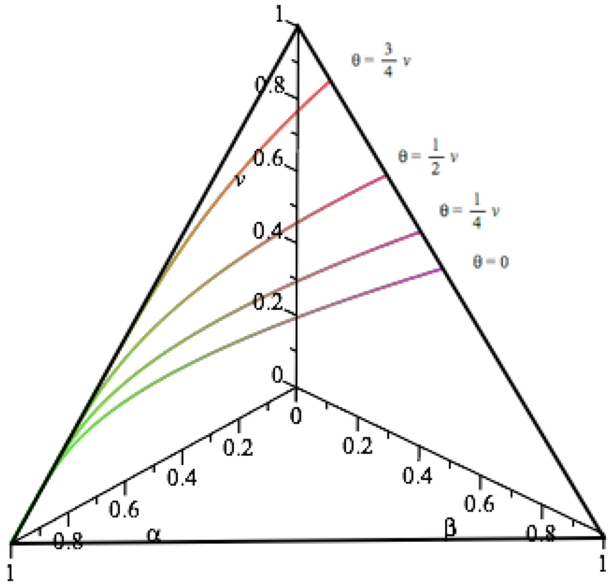

Figure 2.2 – Effect of an increase of θ on sustainability

Proposition 3. *When pollution hurts severely productivity, the contraction area is reduced. The detrimental effect of pollution on production thus enhance sustainability.*

Proof.
$$\frac{\partial\left(\frac{(1+a)^{\frac{1}{\theta-v}}(2+\rho)v}{1-(1+a)^{\frac{1}{\theta-v}}}\right)}{\partial\theta} < 0$$
□

This effect may seems puzzling, it is nevertheless quite intuitive. If sustainability is enhanced while the detrimental impact of pollution on production increases, this is due to the specificity of pollution which is considered here. Firstly, we consider the category of flow pollutants that hurt the current period productivity, and disappear in the next period. Secondly, we do not use the standard assumption that pollution is an externality resulting from production. Here, pollution is an externality coming from the extraction and/or the use of a non-renewable resource in the production. Along the balanced growth path, emissions thus evolve as the resource do, and disappear asymptotically. [12] When time goes by, the resource is used in smaller

12. As previously exposed, those assumptions are realistic for some pollutants (tropospheric ozone, methane, black carbon...).

and smaller amount. The negative impact that natural resources have on productivity through pollution also decreases. The higher is the detrimental effect of pollution on growth, the stronger will be this effect, and the higher is growth on the balanced growth path. [13] That is, when θ increases, it diminishes the adverse effect on growth imposed by the necessary decreasing resource extraction. To say it differently, θ diminishes the net resource's contribution to growth, and thus its implicit negative contribution. Moreover, when θ increases, the BGP extraction rate is lower. It allows the economy to save some resources for the future. In the long run, a lower level of savings is needed to compensate for resource depletion and the condition on the labor share thus eases.

2.2.4 The impact of resource dependence on growth

In this economy economy, v is the income share of natural resources. Indeed, $w_t/y_t = \beta$, $(r_t - \delta)k_t/y_t = \alpha$ and $p_t x_t/y_t = v$.

Indeed, we can calibrate the model in order to show that an increase in v is associated with a lower balanced growth rate. The derivative of growth with respect to the resource share is:

$$\frac{\partial \mu}{\partial v} = \mu \left[\frac{ln(1-q)}{1-\alpha} - \frac{\partial q}{\partial v} \frac{v-\theta}{(1-q)(1-\alpha)} \right] \tag{2.24}$$

Restricting our analysis to positive growth area, we can represent in the $(v, q, \frac{\partial \mu}{\partial v})$ space this derivative with respect to all possible v and q values. [14]

The numerical exercise represented in figure 2.3 shows that an increase in resource dependence (the income share of natural resources) is associated with a lower growth rate. Because of the exhaustibility of the resource stock, a given growth rate implies to save more and more on

13. Using a numerical approach, appendix A.22 shows that an increase in θ increases the rate of growth for reasonable parameter values.

14. A sensitivity analysis has been performed. This result is robust to variation of parameter values in a reasonable range.

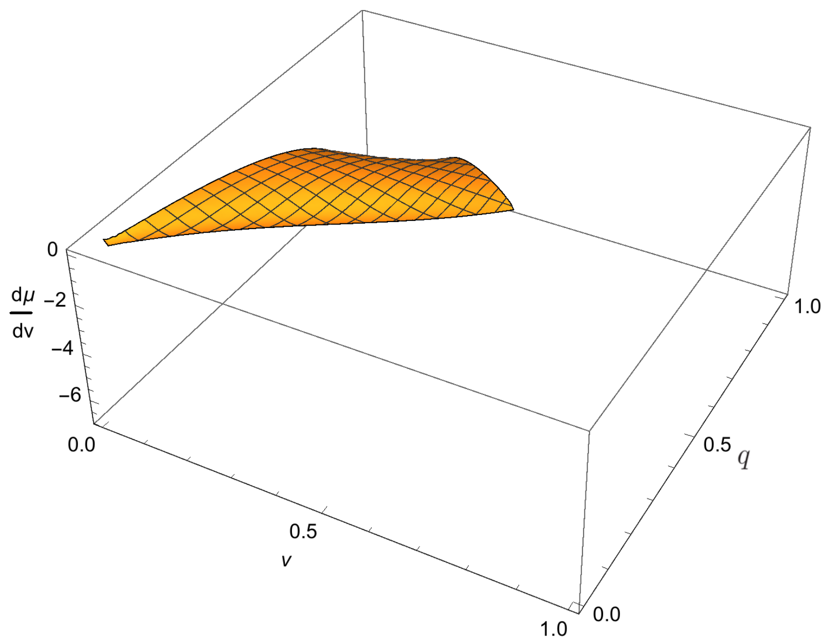

Figure 2.3 – $\frac{\partial \mu}{\partial v}$ for $a = 0.028$, $\delta = 0.027$, $\rho = 0.016$, $\theta = 0.01$, $\alpha = 0.3$

the resource. In itself, it implies that natural resources have a negative contribution to growth. It is not surprising that when the importance of the resource in production increases, this negative contribution increases. However, the constant returns to scale assumption has been lost.To keep the constant returns to scale assumption, an increase in v necessarily implies a decrease in either β or α by the same order (or both obviously). The effect of a change in either β or α are reported in appendix A.23 . Results show that an increase in v compensated by a decrease in α or a decrease in β is associated with a lower balanced growth for reasonable parameter values. Keeping constant returns to scale does not change the result. Note that if an increase in resource dependence depresses growth, an increase in resource abundance (i.e. higher initial endowment) affect positively the level of income reached at each date.

This results directly come from the Euler equation and the non-arbitrary condition between the capital and the resource. Indeed, combining (2.8) and (2.9) and evaluating the right hand side on the BGP, we can write :

$$(1+\rho)\frac{d_{t+1}}{c_t} = \mu_k^{\alpha}\mu_x^{v-\theta-1}$$

For a given extraction rate, an increase in v (or a decrease in θ) implies a decrease in the return of capital (or resource). Households then choose to increase their consumption while young and they reduce their savings and thus capital accumulation. Nevertheless, a change in those parameter causes a change in the extraction rate that may overcompensate the present result. The numerical simulation shows however that this is unlikely for reasonable parameter values since growth decreases with v.

2.3 The Ramsey Economy

2.3.1 The Model

Let's consider a benevolent social planner assumed to solve the following Ramsey problem:

$$\max_{\{c_t;d_t;m_t;k_t;e_t\}_{t=0}^{\infty}} = \frac{1}{1+\rho}ln(d_0) + \sum_{t=0}^{\infty}\frac{1}{(1+\gamma)^{t+1}}\left[ln(c_t) + \frac{1}{1+\rho}ln(d_{t+1})\right]$$

subject to:

$$y_t = A_t k_t^{\alpha} x_t^{v} e_t^{-\theta} \tag{2.25}$$

$$y_t = c_t + d_t + k_{t+1} - (1-\delta)k_t \tag{2.26}$$

$$A_{t+1} = (1+a)A_t \tag{2.27}$$

$$e_t = \phi x_t \tag{2.28}$$

$$m_t = (1-q_t)m_{t-1} \tag{2.29}$$

$$x_t = q_t m_{t-1} \tag{2.30}$$

$$m_{-1} = \sum_{t=0}^{\infty} q_t m_{t-1} \tag{2.31}$$

$$k_0,\, m_{-1},\, e_{-1},\, A_0 > 0\,\text{given}, \tag{2.32}$$

where γ is the social discount rate. (2.25) represents the production function. (2.26) established that the economy consumes or invests exactly its net production in each period. (2.27) represents the exogenous technological progress. (2.28) is the emissions implied by the resource use while (2.29) and (2.30) represents the dynamics of the resource. (2.31) is a total exaustibility condition for the resource while (2.32) represents initial endowments.

The FOC of the previous problems may be reduced to:

$$\frac{1+\gamma}{1+\rho} = \frac{d_t}{c_t} \tag{2.33}$$

$$(1+\rho)\frac{d_{t+1}}{c_t} = \alpha A_{t+1} k_{t+1}^{\alpha-1} x_{t+1}^{v} e_{t+1}^{-\theta} + 1 - \delta \tag{2.34}$$

$$\frac{A_{t+1} k_{t+1}^{\alpha} x_{t+1}^{v} e_{t+1}^{-\theta}(v x_{t+1}^{-1} + \phi\theta e_{t+1}^{-1})}{A_t k_t^{\alpha} x_t^{v} e_t^{-\theta}(v x_t^{-1} + \phi\theta e_t^{-1})} = A_{t+1}\alpha k_{t+1}^{\alpha-1} x_{t+1}^{v} e_{t+1}^{-\theta} + 1 - \delta \tag{2.35}$$

$$\lim_{t\to\infty} \left(\frac{1}{1+\gamma}\right)^t \frac{k_{t+1}}{c_t} = 0 \tag{2.36}$$

(2.33) is an intergenerational optimality condition establishing that the marginal rate of substitution between consumption of young and old has to be equal to one. (2.34) is an intragenerational optimality condition which states that the marginal rate of substitution between consumption while young and consumption while old has to be equal to the marginal product of physical capital net of depreciation. (2.35) characterize the optimal inter-temporal resource allocation which indicates that the depletion of the resource stock implies a implicit return equal to the physical capital return. This condition implies that the economy should satisfy the Hotelling rule. (2.36) is the transversality condition associated with the planner problem.

Combining (2.25)-(2.36) we can define the balanced growth path of this Ramsey economy.

Proposition 4. *The optimal balanced growth path is defined by:*

$$\tilde{\mu}_k = \tilde{\mu}_y = \tilde{\mu}_c = \tilde{\mu} \tag{2.37}$$

$$\tilde{\mu}_x = \tilde{\mu}_e = \tilde{\mu}_m = 1 - \tilde{q} \tag{2.38}$$

$$\tilde{\mu}_a = 1 + a \tag{2.39}$$

$$\tilde{\mu} \ = (1+a)^{\frac{1}{1-\alpha}}(1-\tilde{q})^{\frac{v-\theta}{1-\alpha}} \tag{2.40}$$

Proof. Proof is reported in appendix A.24 . □

Using (2.33), (2.34), (2.35), we have $(1+a)\tilde{\mu}_k^{\alpha}\tilde{\mu}_x^{v}\tilde{\mu}_e^{-\theta}\tilde{\mu}_x^{-1} = (1+\gamma)\tilde{\mu}_c$. Since $\tilde{\mu}_c = \tilde{\mu}_k$, it can be established that $\tilde{q} = \frac{\gamma}{1+\gamma}$. Thus, the optimal extraction rate only depends on the social rate of time preference. A higher social preference for the present implies a higher depletion rate of the resource stock, and a lower growth. To put it differently, a society which strongly cares about future generations is more conservative and achieve a larger rate of growth.

To decentralize the optimal balanced growth path, a government should find an instrument able to put the extraction rate at the optimal level $\frac{\gamma}{1+\gamma}$, keeping the rate of growth of other variables at their optimal level. In section 2.4, we will compare the ability of two scenarios of resource attribution in decentralizing the optimal allocation.

It appears that the optimal policy crucially depends on the social rate of time preference. Indeed, since pollution is modeled as a flow, it is not distortive on the balanced growth path. The only market failure is linked to the demographic structure imposed by the OLG framework: the existence of future generations is not taken into account by the current market economy. Thus, a critical parameter for policy making is the social rate of time preference. The amplitude and existence of a positive social discount rate is widely discussed in the literature. In our OLG framework, the social planner takes into account the fact that agents discount their own utility. The social rate of time preference thus reflects solely the weight that the central planner attaches to each generation. One may argue that the central planner shouldn't favor closer in time generation. In such a case, the policy maker should choose $\gamma = 0$ (Ramsey, 1928; Pigou, 1932; Solow, 1986). Nevertheless, the uncertainty about future economic conditions argue for positive discount rate. For example, our framework is not robust to the existence of a backstop technology that may appear in the future and which will modify the production function (resource may becomes unnecessary in the future). Since this is likely to happen in the very long run, a positive social discount rate allow to avoid an overweighting of distant generations' welfare. Moreover, the existence of far distant generations is not guaranteed. Before looking at the optimum decentralization procedures, one should analyze how changes in important parameters affects the optimal balanced growth path.

2.3.2 Comparative Statics

This section analysis how movements in θ and v impact the optimal rate of growth. We begin by looking at the impact of θ on the rate of growth.

$$\frac{\partial \tilde{\mu}}{\partial \theta} = -\frac{(1+a)^{\frac{1}{1-\alpha}}(1-\tilde{q})^{\frac{v-\theta}{1-\alpha}}\log(1-q)}{1-\alpha} > 0 \tag{2.41}$$

Proposition 5. *The optimal long run rate of growth increases with the detrimental effect of pollution.*

θ diminishes the net resource contribution to production. Mechanisms are similar to those previously exposed. When time goes by, the resource, which is not reproducible, will be used in ever small amount. Thus, when θ increases, it decreases the detrimental effect caused by the need to keep diminishing resource extraction. That leads to a higher growth rate of the economy. Note that contrary to what happens in the market equilibrium, an increase in θ does not decrease the extraction rate in the Ramsey economy. The increase in growth is uniquely due to a diminishing resource contribution to growth. While a higher θ causes a higher growth rate, the level of production may decrease for some instant of time when θ increases due to a contemporaneous adverse effect on production.

Let's consider now a variation of resource dependence. In such a model, resource dependence is characterized by the resource share of output v. In order to keep constant returns to scale, an increase in v should be compensated by an equivalent decrease of either β or α, or both.

Let's consider that an increase in v is compensated by a decrease in β such that returns to scale are kept constant.

$$\frac{\partial \tilde{\mu}}{\partial \beta} = 0 \tag{2.42}$$

$$\frac{\partial \tilde{\mu}}{\partial v} = \frac{(1+a)^{\frac{1}{1-\alpha}}(1-\tilde{q})^{\frac{v-\theta}{1-\alpha}}\log(1-q)}{1-\alpha} < 0 \tag{2.43}$$

Now, imagine that an increase dv of v is compensated by an equivalent decrease $d\alpha$ of α such that $dv = d\alpha$. The total impact on the balanced growth rate will be:

$$\begin{aligned}\frac{\partial \tilde{\mu}}{\partial v}dv - \frac{\partial \tilde{\mu}}{\partial \alpha}d\alpha = {} & \frac{(1+a)^{\frac{1}{1-\alpha}}(1-\tilde{q})^{\frac{v-\theta}{1-\alpha}}\log(1-q)}{1-\alpha}dv \\ & - \frac{(1+a)^{\frac{1}{1-\alpha}}(1-\tilde{q})^{\frac{v-\theta}{1-\alpha}}(v-\theta)\log(1-q)}{(1-\alpha)^2}d\alpha \\ & - \frac{(1+a)^{\frac{1}{1-\alpha}}(1-\tilde{q})^{\frac{v-\theta}{1-\alpha}}\log(1+a)}{(1-\alpha)^2}d\alpha < 0\end{aligned} \tag{2.44}$$

Proposition 6. *The optimal long run rate of growth decreases with resource dependence.*

This result comes from the scarcity of the resource which imposes to the economy to save more and more on the resource stock in order to avoid complete exhaustion in finite time. In itself, this gives a negative resource contribution to growth. When v increases, the importance of the resource in the production increases, the negative contribution of the resource exhaustibility to growth is higher.

Those results are direct outcomes of equation (2.34) and (2.35). Combining those equations, we can write

$$(1+\rho)\frac{d_{t+1}}{c_t} = \frac{A_{t+1}k_{t+1}^{\alpha}x_{t+1}^{v}e_{t+1}^{-\theta}(vx_{t+1}^{-1}+\phi\theta e_{t+1}^{-1})}{A_t k_t^{\alpha}x_t^{v}e_t^{-\theta}(vx_t^{-1}+\phi\theta e_t^{-1})}$$

Evaluating the right hand side of this equation at the BGP leads to:

$$(1+\rho)\frac{d_{t+1}}{c_t} = (1+a)\tilde{\mu}_k^{\alpha}\tilde{\mu}_x^{v-\theta-1}$$

Since $\tilde{\mu}_x \in (0,1)$, is not affected by a change in either v or θ, we can infer that an increase in v or a decrease in θ cause a decrease in the right hand side of the last equation, which represents the rate of return of capital (and resource) on the BGP. Present consumption thus increases at the expense of future consumption, and capital accumulation decreases, leading to a lower growth.

2.4 Decentralizing the Ramsey Optimal Balanced Growth Path

OLG model with a pollution externality are often associated with two market failures. The first one linked to the pollution, the second one linked to the demographic structure of the OLG economy. Concentrating on BGP, it appears from propositions 2 and 4 that pollution doesn't distort the economy because the flow pollution we are considering evolves at the extraction rate. OLG economies are also known to allow for possible capital over-accumulation, which enables the implementation of Pareto improving policies. Nevertheless, Rhee (1991), and Gerlagh & Keyzer (2001) have shown that OLG economies endowed with a finite non-renewable resource are efficient in the Pareto sense, and this results is robust in the model we are using here (Agnani *et al.* , 2005).

The present section aims at surpassing the Pareto efficiency criterion previously used in the literature. We are thus interesting in policies that are able to decentralize the Ramsey optimal allocation for a given social discount rate calibrated by the policy maker to reflect intergenerational fairness. Looking at proposition 2 and 4, it immediately appears that decentralization of the BGP requires to put the market extraction rate at its optimal $\tilde{q}$ level letting other growth determinants unchanged. [15] We propose two ways of decentralization: a tax on resource use and extraction, and to let resource management to a public fund constrained by an extraction rule.

2.4.1 Tax on the private resource

A way that may be used to decentralize the optimal Ramsey equilibrium is to tax the resource used in the production, and to redistribute this income to the young generation as a transfer. Since the resource is taxed, equation (2.16) becomes:

$$p_t + \tau_t = vA_t k_t^{\alpha} x_t^{v-1} e_t^{-\theta} \tag{2.45}$$

where τ_t is the tax rate set by the government in t. The tax is redistributed to the young generation as a transfer g_t such that the government budget is balanced: [16]

$$\tau_t x_t = g_t \tag{2.46}$$

15. Results obtained in this section only apply to the BGP and should not be translated outside.
16. Considering that the tax is invested and then redistributed to old households leads to the same results.

The budgetary constraint of the young agent (2.5) is thus modified as follow:

$$g_t + w_t = c_t + s_t + p_t m_t \tag{2.47}$$

Proposition 7. *If the tax and the resource price increase at the same rate, the balanced growth path of the economy is not distorted by the tax.*

Proof. Proof is reported in Appendix A.25 . □

Proceeding as in section A.21 we can write the market clearing condition as

$$k_{t+1} = A_t k_t^{\alpha} x_t^{v} e_t^{-\theta} \left[\frac{\beta}{2+\rho} - \frac{v(1-q)}{q}\right] + \frac{\tau_t x_t}{2+\rho} \tag{2.48}$$

Dividing both side by k_t, it leads to

$$\mu_k - \frac{\tau_t x_t}{(2+\rho)k_t} = A_t k_t^{\alpha-1} x_t^{v} e_t^{-\theta} \left[\frac{\beta}{2+\rho} - \frac{v(1-q)}{q}\right] \tag{2.49}$$

Since the tax and the resource price increase at the same rate, the fiscal revenues grow at a rate, $\mu_{x\tau} = \mu_k$, and $\frac{\tau_t x_t}{k_t}$ is constant on the BGP. Let ξ denote this constant. Evaluating (2.25) on the BGP leads to

$$\frac{(1+a)^{\frac{1}{1-\alpha}}(1-q)^{\frac{v-\theta}{1-\alpha}}\alpha(2+\rho)q - \xi\alpha q}{\beta q - v(1-q)(2+\rho)} = (1+a)^{\frac{1}{1-\alpha}}(1-q)^{\frac{v-\theta}{1-\alpha}-1} - (1-\delta) \tag{2.50}$$

Comparing (2.50) with its counterpart without tax (2.23) it appears that RHS has not been impacted by the tax. Nevertheless, the LHS of equation (2.23) has been modified by the existence of the resource tax. LHS of equation (2.50) is defined for $q \in [0, \hat{q}[U]\hat{q}, 1]$ with $\hat{q} = \frac{v(2+\rho)}{\beta+v(2+\rho)}$. Since $\tilde{q} = \frac{\gamma}{1+\gamma}$ the Ramsey equilibrium is not decentralizable for $\gamma = \frac{v(2+\rho)}{\beta}$.

Below the threshold $\hat{q}$, the derivative of LHS(q)>0 for a sufficient level of resource taxation

$\hat{\xi}$, $\lim_{q\to 0}(q) = 0$ and $\lim_{q\to \hat{q}}(q) = +\infty$, where

$$\hat{\xi} = v^{-1}(1+a)^{\frac{1}{1-\alpha}}(1-q)^{\frac{v-\theta}{1-\alpha}}[\beta q(v-\theta) - v(2+\rho)(1-q)(v-\theta) + v(2+\rho)] > 0 \quad (2.51)$$

Thus, if $0 < \tilde{q} < \hat{q}$, there exists a level $\xi > \hat{\xi}$ such that the Ramsey equilibrium is decentralizable.

Above the threshold $\hat{q}$, the derivative of LHS(q)<0 for a sufficiently low level of resource taxation $\hat{\xi}$, $\lim_{q\to \hat{q}}(q) = +\infty$ and $\lim_{q\to 1}(q) = -\frac{\xi\alpha}{\beta}$. Thus, if $\hat{q} < \tilde{q} < 1$, there exists a level of $\xi < \hat{\xi}$ which decentralizes the Ramsey optimal equilibrium.

From equation (2.50) the optimal taxation may be obtained:

$$\tilde{\xi} = -\frac{[(1+a)^{\frac{1}{1-\alpha}}(1-\tilde{q})^{\frac{v-\theta}{1-\alpha}-1} - (1-\delta)][\beta\tilde{q} - v(2+\rho)(1-\tilde{q})] - (1+a)^{\frac{1}{1-\alpha}}(1-\tilde{q})^{\frac{v-\theta}{1-\alpha}}\alpha(2+\rho)\tilde{q}}{\alpha\tilde{q}} \quad (2.52)$$

where it should be recalled that $\tilde{q} = \frac{\gamma}{1+\gamma}$. Calibrating the model with annual rates of $a = 0.028$, $\delta = 0.027$, $\rho = 0.016$, $v = 0.05$, $\alpha = 0.3$, $\beta = 0.65$, and $\theta = 0.01$, e can characterize ξ for different level of γ. The level of the tax decreases with the social rate of time preference. With the above calibrated values, a negative taxation (i.e. subvention) for resource extraction is required for an annual discount rate of $\gamma > 0.0202$. As previously discussed, a reasonable value for γ is such that $0 < \gamma < \rho$. A subvention becomes necessary when the social planner preferences are oriented in favor of close in time generations, such that he considers that current generations are too conservative. In such a case, the policy maker should subvention the resource use which will decrease the rate of growth. In case of very strong social preference in favor of present, the rate of growth may become negative, leading to (optimal) extinction. This little simulation exercises show that for reasonable annual social discount rate values (i.e. between 0 and 0.016), policy makers should implement a tax on fossil resource use. In this model with flow pollutants, this tax also helps to fight against pollution and may also be qualified as an environmental tax.

2.4.2 Public property rights on the resource stock

Another way to decentralize the Ramsey optimal BGP is to modify the property rights on the resource stock. Considering that the resource is a common shared by all generations, one may decide that the resource should belong to a trust fund which cares about all generations. On the BGP, this fund should follow an extraction rule such that the resource exhaustion is done at the optimal rate $\tilde{q}$. This fund is the sole supplier of natural resources and thus knows the productive firms demand for this input. We assume that the fund invests the rent from resource extraction and gives a transfer to the old generation as a retirement pension such that its budget is balanced. [17]

In the first period of life, the household works and earn a wage which is used for savings and consumption. The first period budget constraint becomes:

$$w_t = c_t + s_t \tag{2.53}$$

The second budget constraint becomes:

$$d_{t+1} = (1 + r_{t+1})s_t + (1 + r_{t+1})g_t \tag{2.54}$$

We can then derive the inter-temporal budget constraint:

$$w_t = c_t + \frac{d_{t+1}}{1 + r_{t+1}} - g_t \tag{2.55}$$

Maximization of utility with subject to the IBC leads to the Euler equation (2.8), which established that the marginal rate of substitution between the two consumptions is equal to their

17. It is known that letting the resource management to a fund which maximizes the present value of the resource rent is often a way to decentralize the optimal equilibrium (see Conrad, 2010). However, it can be shown that in this model, such a policy is able to decentralize the market equilibrium only if there is no growth, i.e. if the technical progress increases at a rate $a = ((1 + \gamma)/\gamma)^{\upsilon - \theta}$. This is because utility is not derived directly from resource use in the model which takes into account the productive structure of the economy.

relative price.

Competitive productive firms are profit maximizing and their behavior is not modified with respect to previous sections. Thus the demand function from productive firms is thus characterized by the following equation:

$$p_t = vA_t k_t^{\alpha} x_t^{v-1} e_t^{-\theta} \tag{2.56}$$

The trust fund mission is to manage optimally the resource stock according to a rule of extraction. Each period, the resource stock should be exhausted at a rate $\tilde{q} = \gamma/(1+\gamma)$. Since it is the sole which can offer the non-renewable resource to firms, he knows the demand function that emerge from the firms. Thus it will sold to firms a quantity $\tilde{x}_t = \tilde{q}m_{t-1}$ at each date. Since it is a monopoly, the funds optimal policy is to choose $\tilde{p}$ such that:

$$\tilde{p}_t = vA_t k_t^{\alpha} \tilde{x}_t^{v-1} e_t^{-\theta} \tag{2.57}$$

This allows market to be balanced and do not create distortion in the rest of the economy. Since the budget of the fund should be balanced, we have:

$$\tilde{p}_t \tilde{x}_t = \tilde{g}_t \tag{2.58}$$

The new market clearing condition is:

$$\tilde{g}_t + s_t = k_{t+1} \tag{2.59}$$

Proposition 8. *The trust fund is able to decentralize the Ramsey optimal BGP.*

Proof. Proof is reported in appendix A.26 . □

As shown in appendix A.26 , this policy doesn't distort the balanced growth path and put the growth rate at its optimal level. The reason is simple: the rule implies that the extraction rate is calibrated at its optimal level. The optimal transfer $\tilde{g}$, which is equal to the fund revenues resulting from the implementation of the optimal policy, grows at the same rate than the capital stock. Thus, on the balanced growth path, the market clearing condition is not affected. Wages also grow at the capital stock, so consumption while young should grow at this rate (otherwise, the economy is not on a balanced growth path.) Then the Euler equation implies that consumption while old also grows at this rate. Thus, all variable grow at their optimal rate.

2.4.3 Discussion

I previously provide two solutions in order to decentralize the optimal balanced growth path. In the first case, one can see that a good tax implementation may allow to decentralize the optimal BGP. Nevertheless, implementation of such a tax may face a technical difficulty: if the social rate of time preference is $\gamma = \frac{v(2+\rho)}{\beta}$, a market economy could never reach the optimal extraction rate $\tilde{q} = \frac{v(2+\rho)}{\beta+v(2+\rho)}$. Moreover, we propose to implement a tax by unit extracted. Of course, this proposition is not independent on the modeling framework and should be taken carefully. Smith (2013) remarks that there do not exist two countries which own similar resource tax regimes and that economists' conclusions on those regimes strongly depend on the modeling framework.

The other possibility that we propose is to declare public property rights on the resource stock and then to manage the latter optimally. This policy is likely to be not implementable if property rights on the resource stock are currently privately defined because it necessitates to expropriate one generation. Thus, depending on the current law, countries may choose to implement one or another policy. For example in United States, the owner of a land also own its subsoil assets. In France, the mining code declares that the state own property rights on the subsoil assets. Thus the trust fund policy is easier to implement in France than in United States where the tax policy seems to be a better solution.

The model established that investing the tax revenues and give it to old generations or give it directly to young agents is equivalent. Nevertheless, this is less likely to be true in the real world where young agents are more likely to consume a share of this rent. A safer policy would thus consist in investing the resource rent and give it to agents while retired. This policy is notably followed by The Government Pension Fund Global of Norway. Oil fiscal revenues as well as dividend from the national oil company are placed in the fund which invest them in order to save welfare for future generations. [18] The present work thus provides some theoretical insight that this policy is both ethical and fruitful since it preserves the future of unborn generations and promotes growth.

2.5 Conclusion and general discussion

In this chapter, the model of Agnani *et al.* (2005) is reused and extended. *i*) We show that a flow pollution resulting from resource extraction may help the economy to reach a non-declining consumption path, because it decreases the rate of resource extraction. Thus, pollution diminishes pressure on natural resources. This analytical result is obtained due to the quite restrictive but convenient assumption that pollutants have short lifetime. With stock pollutants coming from the resource use, pollution would follow an inverse U-shaped with respect to time, increasing in a first step due to resource extraction and then decreasing when the extraction rate is very low, due to natural absorption. Thus, the answer of the economy to an increase in the elasticity of production with respect to pollution will be uncertain. Intuition suggests that our results stay true when natural absorption is sufficiently strong to prevent an increase of the stock of pollution. *ii*) Resource dependence reduces growth possibilities, because resource scarcity imposes the economy to save more and more on the resource stock. When resource dependence is high, saving on the resource is harder. *iii*) I analyze the ability of two resource allocation schemes in decentralizing the optimal equilibrium. If the resource is held by the first generation

18. The funds declare on its homepage that "The Government Pension Fund Global is saving for future generations in Norway. One day the oil will run out, but the return on the fund will continue to benefit the Norwegian population." `https://www.nbim.no/en/the-fund/`

of agents, a resource tax redistributed to the young as a transfer generally allow to decentralize the Ramsey optimal equilibrium. If property rights on the resource stock are shared by all generations, an independent trust fund may be able to decentralize the optimal equilibrium. To summarize, the policy that should be implemented depends on the preexisting distribution of property rights in the economy.

Further research may include a model with stock pollution and a ceiling of emission in order to give more accurate policy recommendation. In first stages, pollution will increase due to high resource extraction. While extraction diminishes, the stock of pollution will begin to decrease in some point in time due to natural absorption. The aim of the work will thus be to keep pollution below the threshold. This project may be seen as an extension of Stern *et al.* (2006) where climate change is a byproduct of resource extraction and use only, while in the latter climate change is driven by population, production and consumption. If the present framework is conserved, the work should rely on simulation methods.

Appendices

A.21 Proof of Proposition 2

The proof uses continuously definitions 3 and 4.

— A BGP implies a constant extraction rate. Thus equation (2.2) implies $\mu_m = 1 - q$.

— Equation (2.1) implies. $\frac{q_{t+1}}{q_t} = \frac{x_{t+1}}{x_t}\frac{m_{t-1}}{m_t}$ On the BGP we have $1 = \mu_x/\mu_m$ so $\mu_x = \mu_m$.

— Since emissions are modeled as a linear function of resource use (2.14) $\mu_e = \mu_x$.

— The market clearing condition $s_t = k_{t+1}$ implies $\mu_s = \mu_k$ on the BGP.

— By definition, the technological progress increases at a rate a such that $\mu_a = 1 + a$.

— Evaluating the ratio of production (2.12) in $t + 1$ and in t on the BGP: $\mu_y = (1 + a)\mu_k^\alpha \mu_x^v \mu_e^{-\theta}$.

— From the firms FOC for resource use (2.16) we can compute μ_p.

$$\mu_p = (1 + a)\mu_k^\alpha \mu_x^{v-1} \mu_e^{-\theta} = \frac{\mu_y}{\mu_x}$$

— From the firms FOC for labor (2.15) $\mu_w = (1 + a)\mu_k^\alpha \mu_x^v \mu_e^{-\theta} = \mu_y$

— The non-arbitrary condition between the two assets in the economy (2.9) tells us that $\mu_p = 1 + r_{t+1}$. Thus the interest rate should be constant on the BGP: $\mu_r = 1$

— Since the interest is constant, evaluating the ratio of the Euler equation in $t + 1$ and in t gives $\mu_c = \mu_d$

— Taking the ratio of the firms FOC for capital in $t+1$ and in t gives:

$$\frac{r_{t+1}-\delta}{r_t-\delta}=\frac{\alpha A_{t+1}k_{t+1}^{\alpha-1}x_{t+1}^{v}e_{t+1}^{-\theta}}{\alpha A_t k_t^{\alpha-1}x_t^{v}e_t^{-\theta}}$$

Because the interest rate is constant, evaluating this ratio on the BGP leads to:

$$1=(1+a)\mu_k^{\alpha-1}\mu_x^{v-\theta}$$

Thus:

$$\mu_k=(1+a)\mu_k^{\alpha}\mu_x^{v-\theta}=\mu_y$$

and:

$$\mu_k=(1+a)^{\frac{1}{1-\alpha}}\mu_x^{\frac{v-\theta}{1-\alpha}}$$

— Reintroducing the Euler equation (2.8) in the IBC (2.7) we obtain:

$$w_t=\frac{c_t(2+\rho)}{1+\rho}$$

On the BGP, taking the ratio of the last expression in $t+1$ and in t, we obtain $\mu_c=\mu_w$.

To summarize:

$$\mu_c=\mu_d=\mu_y=\mu_s=\mu_k=\mu_w$$

$$\mu_p=\mu_y/\mu_x$$

$$\mu_a=(1+a)$$

$$\mu_r=1$$

$$\mu_x=\mu_m=\mu_e$$

A.22 Effect of an increase of θ on growth

The effect of an increase in θ is:

$$\frac{\partial \mu}{\partial \theta} = \mu \left[-\frac{ln(1-q)}{1-\alpha} - \frac{\partial q}{\partial \theta} \frac{v-\theta}{(1-q)(1-\alpha)} \right] \tag{60}$$

Restricting our analysis to the positive growth area, we can represent this derivative with respect to all possible values of θ and q in the space $(\theta, q, \frac{\partial \mu}{\partial \theta})$

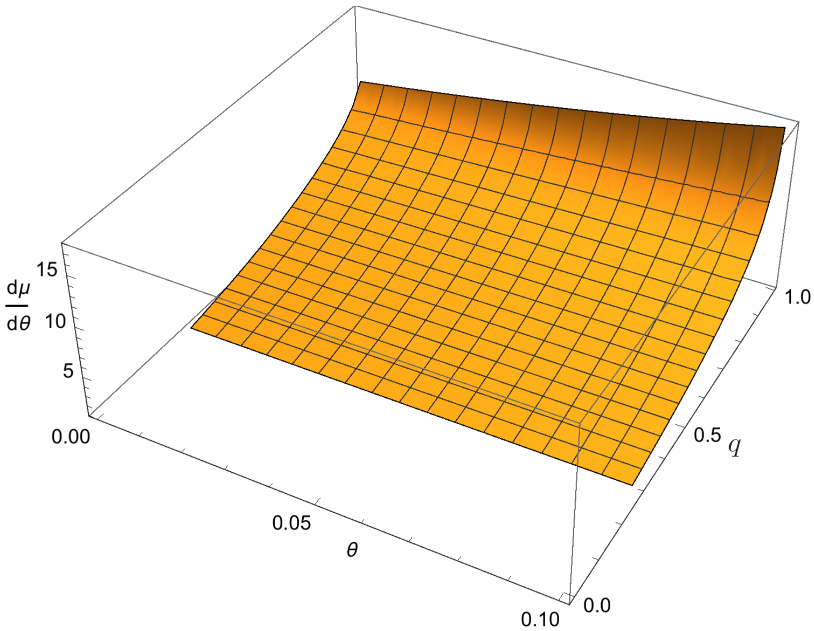

Figure 4 – $\frac{\partial \mu}{\partial \theta}$ for $a = 0.028$, $\delta = 0.027$, $\rho = 0.016$, $v = 0.1$, $\alpha = 0.3$

Proposition 9. *When pollution hurts severely productivity, growth is higher.*

This effect may seems puzzling, it is nevertheless quite intuitive. θ diminishes the net resource's contribution to GDP. The BGP extraction rate is thus lower and that implies that less savings are needed to reach a given growth rate.

A.23 Keeping the constant returns to scale hypothesis

The effect of a change in the labor share on growth is determined by:

$$\frac{\partial \mu}{\partial \beta} = \frac{-(1+a)^{\frac{1}{1-\alpha}}(v-\theta)(1-q)^{\frac{v-\theta}{1-\alpha}-1}}{1-\alpha}\frac{\partial q}{\partial \beta} \tag{61}$$

Since the sign of this expression appears ambiguous, we restrict the analysis on the positive growth area. We then calibrate the model and we show that all possible combinations (β,$q(\beta)$) on the space $GAT < q < PGT$ lead to a positive sign for $\frac{\partial \mu}{\partial \beta}$. The simulation is performed for a wide variety of parameter values and always lead to a positive sign for $\frac{\partial \mu}{\partial \beta}$. Sensitivity analysis has been performed and the result is robust to variation in parameters values. The growth rate of the economy increases with the labor share. An increase in v compensated by a decrease in β leads to a lower growth rate.

The effect of a change in the man-made capital share on growth is determined by:

$$\frac{\partial \mu}{\partial \alpha} = \frac{(1+a)^{\frac{1}{1-\alpha}}(1-q)^{\frac{v-\theta}{1-\alpha}}}{(1-\alpha)^2}\left[ln(1+a)+(v-\theta)ln(1-q)-\frac{(v-\theta)(1-\alpha)\frac{\partial q}{\partial \alpha}}{1-q}\right] \tag{62}$$

Since the sign of this expression appears ambiguous, we restrict the analysis on the positive growth area. We then calibrate the model and we show that all possible combinations (α,$q(\alpha)$) on the space $GAT < q < PGT$ leads to a positive sign for $\frac{\partial \mu}{\partial \alpha}$. The simulation is performed for a wide variety of parameter values and always lead to a positive sign for $\frac{\partial \mu}{\partial \alpha}$. Figure 5 represents an example for given parameter values. Sensitivity analysis has been performed and the result is robust to variation in parameters values. We have characterized possible derivative of μ with respect to α, for all feasible q. Nevertheless τ is endogenously determined by α. Each possible level of α thus lead to one level of q. This combination (α,q) belongs to the plotted surface so it makes no doubt that for reasonable parameter values, growth increases with the capital

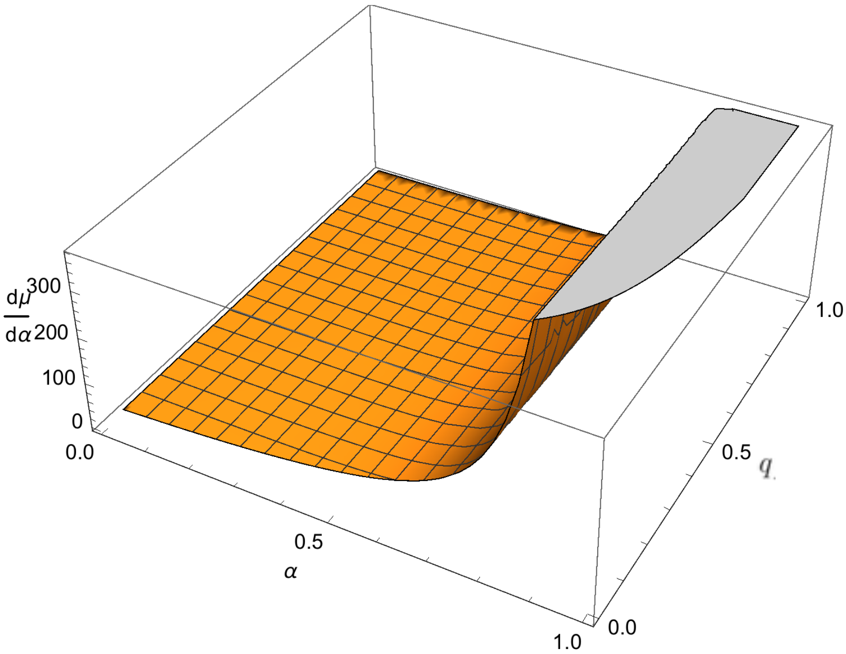

Figure 5 – $\frac{\partial \mu}{\partial \alpha}$ for $a = 0.028$, $\delta = 0.027$, $\rho = 0.016$, $\theta = 0.01$, $v = 0.02$

share. Since a increase in v may imply a decrease in α to keep constant returns, the proposition 5 remains true if the increase in v is compensated by a decrease in α.

A.24 Proof of Proposition 4

- A BGP implies a constant extraction rate. Thus, equations (2.29) and (2.30) imply $\tilde{\mu}_x = \tilde{\mu}_m = 1 - \tilde{q}$.
- Since emissions are modeled as a linear function of extracted resources $\tilde{\mu}_e = \tilde{\mu}_x$.
- By definition, $\mu_a = 1 + a$.
- The ratio of the intergenerational optimality condition (2.33) evaluated in $t+1$ and in t gives on the BGP $\tilde{\mu}_c = \tilde{\mu}_d$.
- The BGP ratio of the production function (2.12) in $t+1$ and t implies $\tilde{\mu}_y = (1 + a)\tilde{\mu}_k^{\alpha}\tilde{\mu}_x^{v-\theta}$.

— The inter-temporal resource allocation optimality condition (2.35) evaluated on the BGP gives:

$$(1+a)\tilde{\mu}_k^{\alpha}\tilde{\mu}_x^{v-\theta-1} - 1 + \delta = \alpha A_{t+1} k_{t+1}^{\alpha-1} x_{t+1}^{v} e_{t+1}^{-\theta}$$

Taking the ratio of the last expression in $t+1$ and in t and evaluating on the BGP, we obtain:

$$1 = (1+a)\tilde{\mu}_k^{\alpha-1}\tilde{\mu}_x^{v-\theta}$$

Thus:

$$\tilde{\mu}_k = (1+a)\tilde{\mu}_k^{\alpha}\tilde{\mu}_x^{v-\theta} = \tilde{\mu}_y$$

and:

$$\tilde{\mu}_k = (1+a)^{\frac{1}{1-\alpha}}(1-\tilde{q})^{\frac{v-\theta}{1-\alpha}}$$

A.25 Proof of proposition 7

Equations (2.1), (2.2), (2.4) (2.10) (2.11) (2.12) (2.14) (2.15) and (2.17) are not modified by the tax. Thus, we can conclude from appendix A.21 that $\mu_x = \mu_m = \mu_e = 1 - q$, $\mu_a = 1 + a$, $\mu_w = \mu_s = \mu_y = \mu_k$ and $\mu_r = 1$. The introduction of the tax and the transfer don't modify the Euler equation or the arbitrary condition between capital and resource in household investment decisions. Thus $\mu_p = 1 + r_{t+1}$ and $\mu_c = \mu_d$.

— If the resource price and the tax level increase at the same rate, taking the ratio of equation (2.45) in $t+1$ and in t gives

$$\frac{\mu_p(p_t + \tau_t)}{p_t + \tau_t} = (1+a)\mu_k^{\alpha}\mu_x^{v-\theta-1}$$

Thus, we can conclude that

$$\mu_p = \frac{\mu_y}{\mu_x}$$

— The IBC with the transfer writes:

$$w_t + g_t = c_t + \frac{d_{t+1}}{1+r_{t+1}} - \frac{p_{t+1}m_t}{1+r_{t+1}} + p_t m_t$$

Substituting equations (2.8) (2.15), (2.46) and taking into account that the resource price increase at the interest rate, we can write:

$$\beta A_t k_t^{\alpha} x_t^{v} e_t^{-\theta} + \tau_t x_t = \frac{c_t(2+\rho)}{1+\rho}$$

Taking the ratio of the last expression and evaluating on the BGP, we obtain:

$$\mu_c = \frac{\mu_k \beta A_t k_t^{\alpha} x_t^{v} e_t^{-\theta} + \mu_p \mu_x \tau_t x_t}{\beta A_t k_t^{\alpha} x_t^{v} e_t^{-\theta} + \tau_t x_t}$$

Since $\mu_p \mu_x = \mu_k$, we have $\mu_c = \mu_k$.

A.26 Proof of proposition 8

- The resource management fund follows a rule and should extract a quantity $\tilde{q}$ at each period. Thus, we have $\mu_x = \mu_e = \mu_m = 1 - q$.
- As in appendix A.21 , $\mu_a = 1 + a$, $\mu_y = \mu_w = (1+a)\mu_k^{\alpha}\mu_x^{v-\theta}$.
- The FOCs of the household problem are not affected by the tax. Thus, the resource price $\tilde{p}$ should grow at the interest rate, and the growth rate of young and old consumption is the same. Thus we have $\mu_{\tilde{p}} = (1 + r_{t+1})$ which implies that $\mu_r = 1$ and $\mu_c = \mu_d$.
- The firm FOC for resource use is now $\tilde{p}_t = v A_t k_t^{\alpha} \tilde{x}_t^{v-1} e_t^{-\theta}$. As in appendix A.21 , we can deduce that $\mu_{\tilde{p}}\mu_{\tilde{x}} = \mu_y$.
- Equation (2.58) implies $\mu_{\tilde{g}} = \mu_{\tilde{p}}\mu_{\tilde{x}} = \mu_y$.
- The firm FOC for capital leads to $\mu_k = \mu_y = (1+a)^{\frac{1}{1-\alpha}}(1-\tilde{q})^{\frac{v-\theta}{1-\alpha}}$.
- The new market clearing condition (2.59) thus implies $\mu_s = \mu_k$.

— Since savings and consumption grow at the same rate, consumption of young should also grow at this rate on the BGP . Thus, equation (2.53) implies $\mu_c = \mu_y$.

Chapitre 3

Threshold Regressions for the Resource Curse [1]

3.1 Introduction

Following the seminal work of Sachs & Warner (1995), a huge literature has developed on the so-called resource curse. The latter refers to the paradox that resource-abundant countries experience lower long run economic growth than do resource-poor countries. Several transmission channels have been identified in the literature to explain the resource curse. Those channel may be classified in two categories. Some rely on *economic* mechanisms while others rely on *political* explanations.

Among economic transmission channels, the most popular is the "Dutch disease" and has been widely documented in the literature (see for example Corden, 1984; Krugman, 1987; Bruno & Sachs, 1982; Torvik, 2001; Matsen & Torvik, 2005). This refers to the over-evaluation

1. This chapter has been written in collaboration with Djamel Kirat (LEO). It reuses contents published in Clootens & Kirat (2017). I would like to thank *Economics Bulletin* for its liberal policy concerning reproduction.

of the local currency that follows the discovery and exploitation of a new important resource deposit. The local currency appreciation causes a loss of competitiveness for the secondary and the tertiary sector which are the engine of growth. Indeed, increasing returns to scale and positive externalities are more likely to appear in the secondary and tertiary sector than in the primary one. Moreover, the mining industry is largely an enclave industry. Thus the extraction of mineral resources *per se* will have relatively few positive spin-off on the overall economy (Davis & Tilton, 2005; Humphreys *et al.* , 2007). The existence of abundant natural resources may also crowd-out investment in human capital. Indeed, they can increase the agent's opportunity cost to invest in human capital (Gylfason, 2001; Sachs & Warner, 1999). A natural resource discovery also shifts investment from the secondary and tertiary sectors to the extractive industry, less prone to generate productivity gains (Sachs & Warner, 1995). To conclude with economic channel, resources prices volatility may negatively impact growth. Indeed, resource-rich economies principal source of revenues often come from the extractive sector. However, resources prices may vary a lot affecting the ability of government to successfully manage their rent. In addition, the macroeconomic instability that results from the resources prices volatility discourages investment (Van der Ploeg & Poelhekke, 2009, 2010; Daniel, 1992).

Alongside with those economic hypotheses come the political hypotheses. Firstly, natural resources generate rents which may be misused. The existence of a resource rent allow to avoid or postpone unpopular but necessary structural reforms. This rent may also be used in order to do unproductive welfare expenditures (Bomsel, 1992). Ross (1999) thus explains that nationalized mining companies may have also softened the budget constraint of resource exporting government, producing fiscal laxity and a tendency to over-borrow. Natural resources may also promote the establishment of weak institutions. Indeed, resource rich countries are often characterized by centralized power and collusion between public authorities and the mining industry. In addition, resource revenues may be used in order to mollify dissent, repress opposition and to avoid accountability pressure (Karl, 1999). Inside week institutions, natural resources provoke rent-seeking behaviors by political interest groups. Those groups often ask for transfers which are not equated with economic contributions or social values. Corruption also often hurts resource rich economies. Indeed, politicians are often suspected to embezzle rent to expand their personal wealth or to accept bribes from third persons who want to get or conserve access to the rent. Finally, natural resources may generate conflicts on greed or grievance motives. Greed theory assesses that rebels begin war in order to access to or to secure resource revenues. The grievance theory suggests that rebels are motivated by the increase in inequalities that follows a resource boom (caused by rent-seeking, corruption and so on...). According to the grievance theory, social justice is thus the main motive of conflicts. Obviously, causes of war are often multidimensional and among other there are natural resources. Anyway, it has been show that natural resources often cause longer war providing revenues to belligerent.

Apart from this literature on the transmission channels of the resource curse, there are great debates over the evidences for the resource curse. Those debates are mainly driven by the fact that resource rich countries have diverse experiences. While Nigeria's oil revenues increased considerably between 1966 and 2010, its real GDP per capita in constant PPP has been multiplied by around 2.2.[2] Symmetrically, Botswana was one of the poorest country in the world while gaining independence in 1966. It has experienced one of the largest growth rate over the four last decades thanks to its diamonds deposits. Its GDP per capita in constant PPP has been multiplied by around 14.8.[3] Nowadays, it is one of the richest African countries and has left the least developed economies group in 1994.[4] Together with Botswana, Indonesia, Malaysia, and Thailand are often cited as developing resource rich economies that achieve a long-term investment ratio larger than one GDP quarter. While some suggests that those countries have escaped from the resource curse, it appears that they perform less well relative to their neighbors endowed with fewer raw materials: Hong-Kong, Singapore and South-Korea (Van der Ploeg, 2011).[5] The World Bank's estimates (Table 3.1) tend to show that the subsoil asset and nat-

2. Its GDP per capita in constant PPP was 2240 $ in 1966, 5030 $ in 2010 (source: PWT9.0).

3. Its GDP per capita in constant PPP was 872 $ in 1966, 12871 $ in 2010 (source: PWT9.0).

4. Since its creation in 1971, five countries have left the least developed economies group: Botswana (1994), Capo Verde (2007), Maldives (2011), Mauritania and Samoa (2014). Nowadays, the group still includes 48 countries.

5. Of course, those differences may be explained by other factors. Notably, James (2015) highlights the im-

ural capital shares are higher in low and middle income economies than in developed ones. Symmetrically, the intangible capital share increases with the level of development.

Table 3.1 – Total wealth and subcomponent in 2005

Income group	Subsoil asset share	Natural capital share	Produced capital share	Intangible capital share
Low-income	6.02%	35.50%	11.31%	53.18%
Middle-income	7.80%	20.57%	19.09%	60.32%
High-income	1.09%	2.50%	17.03%	80.47%
World	2.41%	6.16%	17.32%	72.18%

Notes: Estimates in 2005 U.S. dollars per capita. Source: Own calculation based on World Bank 2011.

In order to investigate the resource curse, growth regressions are often used. The seminal paper by Sachs & Warner (1995) uses growth regressions to show that the natural resource share of exports is negatively associated with economic development. They extend their work in order to show that there is little evidence that the curse is explained by omitted geographical variables (Sachs & Warner, 2001). Atkinson & Hamilton (2003) rely on a closer methodology in order to give evidence that the resource curse may be explained by the incapacity of governments to manage big resource revenues in a sustainable way. Papyrakis & Gerlagh (2004) use growth regressions in order to study the resource curse transmission channels. Alongside these positive analysis, there are also some normative works relying on growth regressions. Among others, Sala-i Martin & Subramanian (2008) rely on growth regressions in order to suggest that resource-rich economies (and Nigeria more precisely) should directly distribute the oil revenues to the population.

The use of growth regressions in this literature often comes with two major problems, as highlighted by Brunnschweiler & Bulte (2008): *i)* natural resource exports over GDP capture resource dependence more than resource abundance, and their use as a proxy for abundance

portance of industry in the economy and show that there is little evidence that resource abundance hampers non-resource growth. His argument is presented in section 3.6.

may lead to the misinterpretation of the regression results (see Figure 3.1); *ii)* introducing resource dependence and institutional variables in growth regressions may produce endogeneity biases: resource dependence is related to economic choices that simultaneously affect growth. Natural resources may also reduce institutional quality, which in turn affects resource dependence through the economic policies that depend on institutions. They address this endogeneity problem via Three Stage Least Squares (3SLS) regressions using historical openness and the presidential regime in 1970s as instruments for resource dependence, while institutional quality is instrumented by latitude.[6] They conclude that resource abundance has a positive effect on economic growth while resource dependence has no effect: the resource curse may then be a red herring.

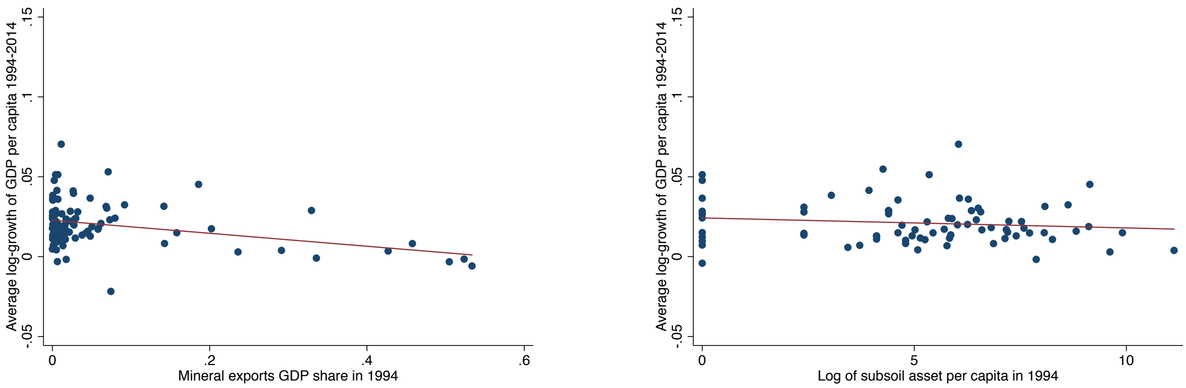

Figure 3.1 – Economic growth, resource dependence and resource abundance

Brunnschweiler & Bulte (2008) introduce regional dummies to pick up the differences in average economic growth across regions, conditional on the other explanatory variables. However, this choice of regions needs to be discussed and justified, as countries in the same region are very heterogeneous regarding climate, geology, culture, politics and economics. Using the same dataset, Clootens & Kirat (2017) show that the impact of resource dependence on growth turns to be strongly negative and significant when we omit the regional dummies.[7] Moreover,

6. Other popular instruments are also used in robustness check regressions. The results remain unchanged.
7. Results from this paper are reported in Appendix A.33.

the way in which Brunnschweiler & Bulte (2008) take into account regional heterogeneities constrains the model parameters (apart from the constant) to be the same across regions. Durlauf & Johnson (1995) show that the linear model commonly used to study growth behavior may be misspecified and they argue for a multiple regime alternative.

Clootens & Kirat (2017) relax this linearity assumption and allow all estimated parameters to vary across regions. They split the sample into two distinct regions, Northern and Southern countries. [8] As this split is subjective, they also investigate OECD versus non-OECD countries. They obtain the following results [9]: southern (non-OECD) and northern (OECD) economies do not behave in the same way with respect to resource dependence: resource dependence cut down growth in low-income economies (see also Figure 3.2 and 3.3).

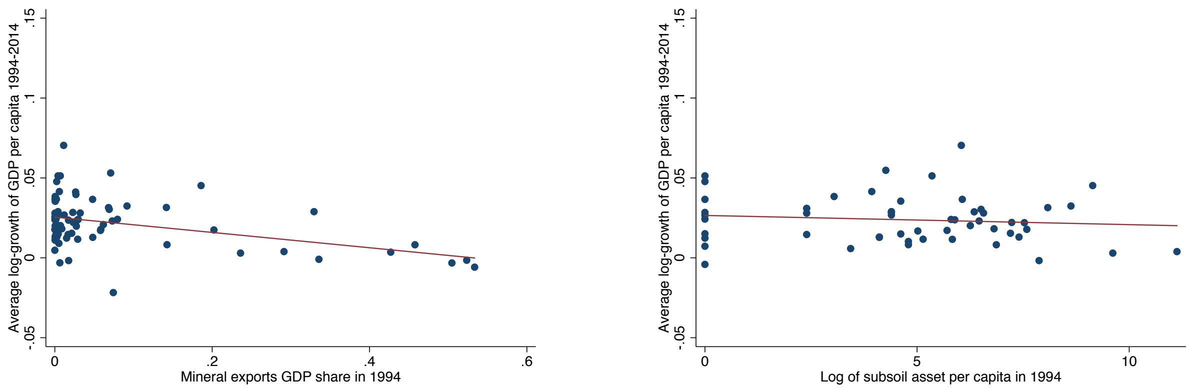

Figure 3.2 – Economic growth, resource dependence and resource abundance in non-OECD countries

8. This split is carried out using the areas in Brunnschweiler & Bulte (2008). Northern countries include North-American, European and Central-Asian countries. They do not investigate African and Middle Eastern countries versus the rest of the world separately as the subsample of African and Middle Eastern countries contains too few observations.

9. Those results are reported in Appendix A.33.

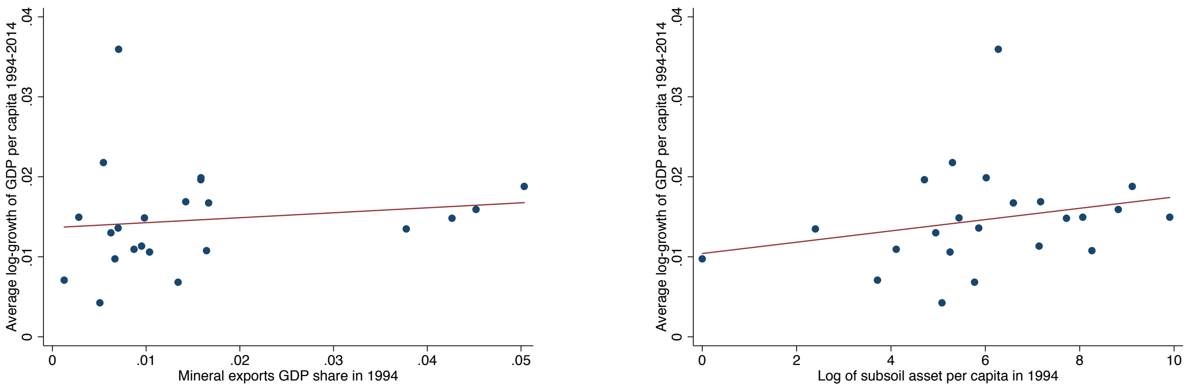

Figure 3.3 – Economic growth, resource dependence and resource abundance in OECD countries

The sample splitting in Clootens & Kirat (2017) is subjective, and calls for a proper sample splitting methodology. Konte (2013) argues that the impact of natural resources on growth may depends on the growth regime to which the country belongs. Using mixture of regressions method, she shows that natural resources increase growth in some countries, and decrease growth in other ones. Also, the level of democracy seems to be the main determinant to explain the belonging to the blessed group. In this chapter we propose to use Hansen (2000)'s sample splitting methodology. [10] It allows to test for a threshold effect and estimates that threshold endogenously. We believe that our methodology has an noticeable advantage: it allows to correct for a possible endogeneity bias provided that our splitting variable is exogenous. Using two different datasets, we find that there exists a value of initial GDP that splits the sample into two subsamples. Since initial GDP might not suffer from endogeneity, we estimate the threshold and run regressions on our subsamples. Using this methodology confirms the previously obtained results: resource dependence slows down growth in low-income economies while resource abundance seems to be a blessing. Nevertheless, we then propose to alert the reader on the limits of this cross-country analysis. In a robustness section, we question the accuracy

10. Caner & Hansen (2004) show that this methodology allows to use the instrumental variable estimator instead of the ordinary least square estimator if the model suffer from endogeneity.

of the instrumental procedure providing usual test results. We then proposes to check whether our results are robust to the division of time period into sub-periods characterized by different resources prices path. It appears that in the period of increasing resources prices, the negative impact of resource dependence disappears, but we believe that it only shed little doubt on previously obtained results for several reason, including the use of averaged variables calculated over a small time horizon together with the 2008 economic crisis which should explain a large share of cross-country growth differences. Our results, which come from cross-sections regressions, are more seriously questioned in a discussion section. Indeed, as highlighted by James (2015), the resource curse may be a statistical mirage. He notably shows that the crowding-out effect often used by economists to explain the resource curse is not verified. In addition James & James (2011) show that an important – slow growing – resource sector may artificially diminish the growth performance of an economy even if the income trajectory with resources dominates the trajectory without resources. We strongly believe that those arguments contrast our cross-country results. Moreover, since our analysis only report cross-country regressions without allowing to test for transmission channels, we decide to discuss cross-sectional heterogeneity and to illustrate that the curse underlying mechanisms may be very different using Zambia and Sierra Leone as examples.

The rest of the chapter is organized as follows. Section 2 describes our two datasets. Section 3 presents the estimation strategy. Section 4 presents our results and their interpretations. Section 5 provides the usual test and a robustness check while section 6 concludes.

3.2 Data

In the following, the econometric work will be performed on two separate datasets.[11] One is the dataset used by Brunnschweiler & Bulte (2008) (B&B dataset hereafter) and covers the

11. Sources of data are provided in appendix A.31.

1970-2000 period. The second one (our own dataset) covers the period 1980-2014 and includes new countries. [12]

In B&B dataset, $Growth$ refers to the average log-growth of real (PPP in current \$) GDP per capita between 1970 and 2000. $gdp_{t=0}$ represents the real (PPP in current \$) GDP per capita in 1970. Resource dependence (RD) represents the GDP share of mineral exports (sum of mineral fuels, ores and metal exports [13]) averaged over 1970-1989. Resource abundance (RA) is measured as the log of subsoil asset in \$ per capita in 1994. [14] It includes exhaustively bauxite, copper, hard coal, iron, lead, lignite, natural gas, nickel, oil, phosphate, silver, tin and zinc. $Inst$ captures the effectiveness of contract enforcement, police and the courts, and likelihood of crime and violence in 1996. $pres_{t=0}$ is a dummy variable coded 1 if the regime is presidential, 0 if parliamentary. The first entry in 1970s is retained. Trade openness ($open$) is the (nominal) GDP shares of imports plus exports averaged over 1950s and 1960s.

In our dataset, $Growth$ refers to the average log-growth of real (PPP in constant \$) GDP per capita between 1980 and 2014. The PWT 9.0 provide 5 estimations of GDP. We use the real GDP calculated using national-accounts growth rates, as recommended for growth regressions by Feenstra *et al.* (2015). [15] We also follow Feenstra *et al.* (2015)'s recommendation when we choose our initial GDP variable. We thus consider the real GDP in current PPP in 1980. Indeed, this variable limits the bias that may be introduced by the "constant PPP correction" and is best suited to measure initial GDP. Concerning RA, we use the log of subsoil asset per capita in \$ in 1994 plus one. We thus consider countries with no mineral asset in our regressions. Adding one to the subsoil asset is not so distortive since non-zero values for subsoil asset are quite elevated. Our RD variable is the average GDP share of mineral exports (defined as in the B&B dataset)

12. We reproduce systematically our work on Brunnschweiler & Bulte (2008) database in order to check whether the results are robust and not driven by our own dataset. Moreover, a robustness check has been done using updated data from PWT 9.0 on the period 1970-2000.

13. Fuels represents commodities in Standard International Trade Classification (SITC) 3 while ores and metal comprises goods in SITC 27, 28, and 68.

14. Taking the log replaces 0 by missing values. One may argue that it can cause a distortion of obtained results.

15. PWT 9.0 also includes GDP in constant PPP, in current PPP, estimated from both the demand and supply sides.

over the 1980-2014 period. Our $Inst$ also captures the effectiveness of contract enforcement, police and the courts, and likelihood of crime and violence, but has been averaged over the period in order to give a better representation of the "average" institutional quality during the considered period. For $pres_{t=0}$ we retained the first entry in 1980s. Finally, our trade openness variable is the sum of real (current PPP) GDP shares of imports and exports averaged over the 1970s. We do not consider previous periods in order to obtain a maximum of observations in the database.

Finally, $latitude$ is common to both datasets. It is the latitude in absolute value of a country (its capital) divided by 90 in order to be scaled between 0 and 1.

Table 3.2 – Descriptive statistics

	B&B data				Own data			
	Mean	S.D	Min.	Max.	Mean	S.D	Min.	Max.
$growth(\%)$	5.822	1.789	-0.304	9.807	1.603	1.470	-1.573	6.264
RA	5.793	1.861	2.303	9.908	5.071	2.765	0.000	11.126
RD	0.058	0.091	0.000	0.437	0.064	0.089	0.000	0.489
$gdp_{t=0}$	7.077	0.915	5.493	8.517	8.481	1.160	6.273	10.815
$Inst$	0.391	1.046	-1.270	2.100	0.093	1.065	-1.563	1.953
$pres_{t=0}$	0.552	0.502	0.000	1.000	0.627	0.487	0.000	1.000
$open$	0.426	0.240	0.062	1.194	0.345	0.262	0.020	1.298
$latitude$	0.306	0.199	0.010	0.710	0.280	0.196	0.011	0.711

The list of countries is reported in Appendix A.32. Each dataset contains respectively 58 and 75 countries.

Table 3.2 presents descriptive statistics for both datasets. The first part covers B&B dataset while the second covers our own dataset. In general, there are few variations in our two datasets but some variables exhibit important differences in both subsamples. Notably, $growth$ is quite different. This difference is mainly due to the method of calculation of the variable. Thus, our growth variable is able to take into account the variations of PPP across time following recent Penn World Table progress. [16] The second variable which exhibits a difference between the two

16. The distinction between several GDP variables has been introduced in PWT 9.0. Conversion table to previ-

subsamples is the institutional one. The difference may be due to the inclusion of new countries in our dataset.

3.3 Estimation strategy

3.3.1 The threshold model

The main equation in the linear model considered by Brunnschweiler & Bulte (2008) is very close to the following: [17]

$$Growth_i = \beta_0 + \beta_1 RD_i + \beta_2 RA_i + \beta_3 Inst_i + \beta_4 gdp_{t=0,i} + \varepsilon_i \tag{3.1}$$

This regression can also be written as follows:

$$Growth_i = \Psi X_i + \varepsilon_i \tag{3.2}$$

where $\Psi = (\beta_0, \beta_1, \beta_2, \beta_3, \beta_4)$ and $X_i = (1, RD, RA, Inst, gdp_{t=0})'$. We look for a possible nonlinear effect induced by real GDP per capita in 1970. The choice of the transition variable among explanatory variables when we implement threshold models is a key issue. In many papers, the choice is based on economic theory. We rely on the literature on convergence clubs to consider here initial real GDP per capita as the threshold variable. The idea is to show that there are different trajectories in growth, depending on the initial level of GDP. We believe that such differences may be measured by the asymmetry of the GDP long-run growth relative to initial GDP. [18] Hansen (2000) uses initial GDP as the threshold variable in growth

ous versions exists.

17. We omit the regional dummies.

18. In other papers, the threshold variable is selected using a test procedure based on linearity tests. The procedure applies first linearity tests for each of the explanatory variables. Then, the threshold variable is selected as the one with the lowest risk of error when linearity is rejected. This statistical approach does not have theoretical

regression in order to illustrate its methodology. This idea is inspired by Durlauf & Johnson (1995). Clootens & Kirat (2017) give some proofs that countries react differently to an increase in resource dependence depending on their initial GDP. Thus, we use the following threshold regression model:

$$Growth_i = \begin{cases} \Psi^1 X_i + \varepsilon_i & if \quad gdp_{t=0,i} \leq q \\ \Psi^2 X_i + \varepsilon_i & if \quad gdp_{t=0,i} > q \end{cases} \tag{3.3}$$

where $\Psi^1 = (\beta_0^1, \beta_1^1, \beta_2^1, \beta_3^1, \beta_4^1)$ and $\Psi^2 = (\beta_0^2, \beta_1^2, \beta_2^2, \beta_3^2, \beta_4^2)$. The threshold parameter q is considered to be unknown. It is convenient to rewrite (3.3) as follows:

$$Growth_i = \Psi^2 X_i + \lambda X_i \mathbb{1}_{gdp_{t=0,i} \leq q} + \varepsilon_i \tag{3.4}$$

where $\lambda = \Psi^1 - \Psi^2$. We want to estimate Ψ^1, Ψ^2 and q if the null hypothesis of linearity is rejected, i.e. $H_0 : \lambda = 0$ in equation (3.4).

We first examine the null hypothesis of linearity in equation (3.4), $H_0 : \lambda = 0$. Without an *a priori* fixed value of q in regression (3.4), it is not easy to make any statistical inference regarding λ. In this case q is a nuisance parameter which is not identified under the null hypothesis. To avoid this problem, Hansen (1996) developed a simulation technique producing a p-value statistic for the inference of λ. Their approach does not require fixing an *a priori* value of q and allows for possible heteroskedasticity in (3.4). The computation method of the threshold estimate $\widehat{q}$ uses the concentrated sum of squared errors function from (3.4):

$$S(q) = \sum_{i=1}^{N} \left(Growth_i - \widehat{\Psi^2}(q) X_i - \widehat{\lambda}(q) X_i(q) \right)^2 \tag{3.5}$$

and the threshold estimate $\widehat{q}$ is the value that minimizes $S(q)$:

$$\widehat{q} = \underset{q \epsilon \Gamma}{\arg\min} S(q) \tag{3.6}$$

economic foundations. It presents the disadvantage of selecting a threshold variable which is different from the variable of interest (related to economic theory). For this reason many authors hold our approach.

where Γ is a bounded set of elements of $\{gdp_{t=0,i}, i = 1, ..., N\}$ and can be approximated by a grid (see Hansen, 2000). Finally, the slope estimates in the threshold model (3.3) can be computed via $\widehat{\Psi^2}(\widehat{q})$ and $\widehat{\lambda}(\widehat{q})$. Hansen (2000) and Caner & Hansen (2004) also developed asymptotic distribution theory for the threshold estimate $\widehat{q}$, and proposed asymptotic confidence intervals by inverting the likelihood-ratio statistic. His approach again allows for possible heteroskedasticity in (3.4).

3.3.2 Dealing with endogeneity

While one may want to apply the threshold regression on equation (3.1), our estimation may suffer from an endogeneity bias. Indeed, Brunnschweiler & Bulte (2008) identify several sources of endogeneity that may affect the model. [19]

Firstly, the institutional quality might be not invariant with respect to some of the deep economic variables. Thus, the coefficient on institutions in growth regressions may be biased due to some omitted variables.

Secondly, RD is not a proper explanatory variable in growth regressions because its denominator is the GDP. Thus, it is likely to be correlated with various variables that also determines economic growth. Considering resource dependence as exogenous may thus lead to biased outcomes.

Another concern rely on the exogeneity of the resource abundance suggested by Brunnschweiler & Bulte (2008). Indeed, exploration and evaluation of resource stock is a technological intensive process which is not independent from countries' technological levels. Nevertheless, thanks to their economic potential, mineral deposits have been well explored and estimated by large

19. Also, Haber & Menaldo (2011) argue that cross-country growth regressions for the resource curse may suffer from omitted variable and reverse causality bias. Instrumentation should correct for those bias. Moreover, our sample splitting may reduce the omitted variable bias grouping countries according to their level of income. We nevertheless acknowledge that our results shouldn't be interpreted as law-like statements.

multinational firms regardless of local conditions. While the resource abundance variable is not exempt from criticism [20], we believe that it constitutes an improvement with respect to the standard measure popularized by Sachs & Warner (1995).

Usually the literature uses mainly three alternative instruments in order to correct for the endogeneity bias induced by institutions: latitude, the fraction of population speaking a western European language (Hall & Jones, 1999) and the log of settler mortality (Acemoglu *et al.* , 2001). Latitude and the fraction of population speaking a western language are measures of the extent to which an economy has been influenced by Western Europe, which is the first area which has implemented institutions supportive to production. Nevertheless, these variables are not impacted by current economic performance. [21] As shown by Acemoglu *et al.* (2001) settler mortality is also a good instrument for institutions. Indeed, there were various types of colonization ranked from "extractive states" to "neo-europes" (Crosby, 2004). The feasibility of settlements has affected the colonization strategies such that "neo-europes" appeared where settler mortality was low. Since past institutions is a major determinant of current institutional quality, settler mortality seems to be a good instrument for institutions. In this chapter, latitude is used to correct the endogeneity bias because it is likely that mineral abundance promoted the establishment of extractive states.

Following Brunnschweiler & Bulte (2008), two perspectives on institutions may be distinguished. On the one hand, institutions may be seen as persistent constitutional variables (presidential vs parliamentary regimes, electoral rules...). Indeed, institutions may refer to "deep and durable" characteristics of a society (Glaeser *et al.* , 2004). On the other hand, institutions may also refer to the policy outcome in property right enforcement, fight against corruption and

20. Notably, Bohn & Deacon (2000) remark that economic policies may affect the present value of rents. Van der Ploeg & Poelhekke (2010) are also suspicious concerning the exogeneity of the abundance variable. Since the results obtained by Brunnschweiler & Bulte (2008) are robust to the use of different abundance variables (some of them proposed in the critical paper by Van der Ploeg & Poelhekke, 2010) we do not enter into this debate in the present work.

21. This is especially true for latitude while economic development may affect the current percentage of English speaking people. Nevertheless, this difficulty may be avoided using the proportion of English speaking people in 1970.

so on (Rodrik *et al.* , 2004). As previously explained, our variable $Inst$ refers to the second view, and may suffer from endogeneity while used in our second step estimation. Hence its instrumentation in a first step is necessary.

Deep and durable institutions may be used to instrument for resource dependence. Brunnschweiler & Bulte (2008) use a dummy variable (1 if the country is under a presidential regime in 1970s, 0 otherwise) as a proxy for institutions. Indeed presidentialism is often associated with public expenditures biased in favor of private interest (including the primary sector) because the decision maker doesn't rely on a stable majority. They show that this variable is exogenous. They also suggest to instrument RD using past trade openness and show that it constitutes an exogenous instrument. [22]

Since the threshold estimation may be biased through endogeneity, we should use the corrected RD and $Inst$ variables to test for the threshold. In the chapter, the instrumentation procedure follows Brunnschweiler & Bulte (2008).

3.4 Results

We first perform the threshold test proposed by Hansen (2000) on an instrumented version of equation (3.1):

$$growth_i = \beta_0 + \beta_1 \widehat{RD}_i + \beta_2 RA_i + \beta_3 \widehat{Inst}_i + \beta_4 gdp_{t=0,i} + \varepsilon_i \tag{3.7}$$

where

$$\widehat{RD}_i = \widehat{\psi_0} + \widehat{\psi_1} RA + \widehat{\psi_2} gdp_{t=0,i} + \widehat{\psi_3} latitude_i + \widehat{\psi_4} open_i + \widehat{\psi_5} pres_{t=0,i} \tag{3.8}$$

22. Using the predicted trade shares developed by Frankel & Romer (1999) as an instrument in order to consider the possible endogeneity of the openness measure does not affect their results.

and

$$\widehat{Inst_i} = \widehat{\phi}_0 + \widehat{\phi}_1 RA + \widehat{\phi}_2 gdp_{t=0,i} + \widehat{\phi}_3 latitude_i + \widehat{\phi}_4 open_i + \widehat{\phi}_5 pres_{t=0,i} \tag{3.9}$$

Thus, in equation (3.7), $\widehat{RD}$ and $\widehat{Inst}$ are the predicted values from instrumental regressions (3.8) and (3.9). Figure 3.4 represents the threshold test in both dataset. If the sequence exceeds the 95% critical value, linearity is rejected.

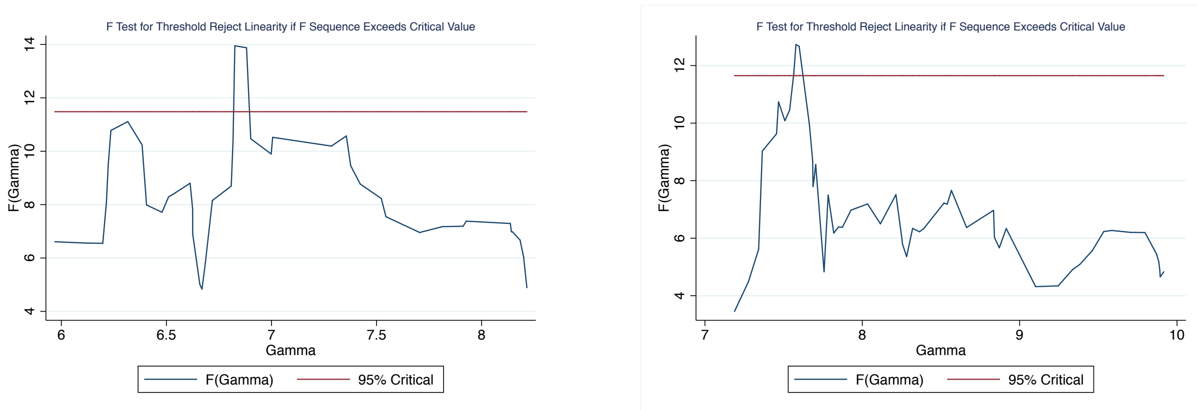

Figure 3.4 – Threshold tests: the IV case

The test rejects the null hypothesis of linearity for both datasets. The reported p-values for the B&B and for our own dataset are respectively 0.022 and 0.049. [23] There exists a threshold value for initial GDP that splits our sample into two different subsamples, consistently with the findings of Clootens & Kirat (2017). Sample splitting estimation should be performed for both datasets.

23. Bootstrapped p-values obtained with 5000 replications. For our own dataset, we perform the test several times. The p-value varies a little between replications, we never find a p-value higher than 0.06.

Table 3.3 – IV regressions by subgroups: B&B dataset

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Economic growth:	All	Low	High	Low^{LB}	High^{LB}	Low^{UB}	High^{UB}
RD	-0.100***	-0.106*	-0.007	0.006	-0.108***	-0.144***	0.004
	(0.036)	(0.064)	(0.025)	(0.057)	(0.033)	(0.054)	(0.020)
RA	0.005***	0.009***	0.000	0.007***	0.004***	0.008***	-0.000
	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)
$Inst$	0.016***	0.027**	0.011**	0.006	0.015***	0.022*	0.012***
	(0.005)	(0.012)	(0.005)	(0.014)	(0.005)	(0.012)	(0.004)
$gdp_{t=0}$	-0.019***	-0.027***	-0.014*	-0.079***	-0.016**	-0.023***	-0.021***
	(0.005)	(0.009)	(0.008)	(0.015)	(0.007)	(0.006)	(0.008)
$cons$	0.159***	0.197***	0.154***	0.492***	0.152***	0.172***	0.216***
	(0.035)	(0.058)	(0.058)	(0.086)	(0.045)	(0.041)	(0.056)
$Threshold$	———	6.826	6.826	6.117	6.117	7.285	7.285
N	58	29	29	9	49	34	24

Notes: Standard errors in parentheses. *,** and *** refer respectively to the 10%, 5% and 1% significance levels. First steps results for the main regressions are reported in Appendix A.35. The threshold is estimated in a 95% confidence interval. Column (4)-(8) reproduce column (2) and (3) at the boundary of the confidence interval.

Table 3.4 – IV regressions by subgroups: Own dataset

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Economic growth:	All	Low	High	Low^{LB}	High^{LB}	Low^{UB}	High^{UB}
RD	-0.064	-0.287**	0.006	-0.287**	0.006	-0.249***	0.004
	(0.039)	(0.124)	(0.035)	(0.124)	(0.035)	(0.095)	(0.034)
RA	0.002***	0.010*	0.000	0.010*	0.000	0.006**	0.000
	(0.001)	(0.006)	(0.001)	(0.006)	(0.001)	(0.003)	(0.001)
$Inst$	0.009**	-0.012	0.010***	-0.012	0.010***	0.007	0.009***
	(0.004)	(0.042)	(0.004)	(0.042)	(0.004)	(0.026)	(0.003)
$gdp_{t=0}$	-0.011***	-0.048**	-0.011***	-0.048**	-0.011***	-0.034***	-0.011***
	(0.003)	(0.024)	(0.003)	(0.024)	(0.003)	(0.012)	(0.003)
$cons$	0.100***	0.337**	0.105***	0.337**	0.105***	0.256***	0.109***
	(0.023)	(0.136)	(0.028)	(0.136)	(0.028)	(0.074)	(0.027)
$Threshold$	———	7.468	7.468	7.468	7.468	7.565	7.565
N	75	16	59	16	59	19	56

Notes: Standard errors in parentheses. *,** and *** refer respectively to the 10%, 5% and 1% significance levels. First steps results for the main regressions are reported in Appendix A.35. The threshold is estimated in a 95% confidence interval. Column (4)-(8) reproduce column (2) and (3) at the boundary of the confidence interval.

Table 3.3 and 3.4 confirm insights given in Clootens & Kirat (2017) on the necessity of sample splitting. Indeed, it appears that poor and rich countries (defined using Hansen (2000)'s methodology) do not behave in the same way with respect to natural resources. In low-income economies, resource dependence is a curse that cuts down growth possibilities while resource abundance is still a blessing. In the B&B dataset, a one percentage point increase in the GDP share of mineral export leads to a decrease by 0.106 percentage point (0.287 in our dataset). Conversely, an one percent increase in subsoil asset is associated to a increase in growth of about 0.009 percentage point (0.010 in our dataset). The negative sign on initial GDP per capita captures a catch-up effect. A one percent increase in initial GDP leads to a decrease in the average growth rate by 0.027 percentage point (0.048 in our dataset). In the B&B dataset, a one percentage point increase in our institutional quality index is associated with an increase in growth of about 0.027 percentage point (no significant effect in our dataset).

In high-income economies, growth is not determined by either dependence or abundance. Institutional quality seems to play a important role while we also find a catch-up effect in both datasets.

The results on mineral dependence contradicts one of the main results given in Brunnschweiler & Bulte (2008): [24] with sample splitting, dependence matters for the development of developing economies. Interpretation may go further. Usually, initial GDP per capita is introduced in growth regression in order to capture a catch-up effect. Here, this variable is also supposed to be the sample splitting variable. Thus, heterogeneity between sub-sample is better taken into account. Implicitly, choosing this variable as the sample splitting one suppose that countries on a side of the threshold share common properties highly determined by development. Notably, it is believed that a country which has a high income per capita in 1970 (or 1980 depending on the dataset) is probably a country which exhibits a market-friendly environment: high level of educated people, developed financial markets, sufficient trade openness, non-observed

24. We believe that our results help to understand the ones that Brunnschweiler & Bulte (2008) obtain. Indeed, they introduce regional dummies in their regression, but the only significant coefficient is on Africa and Middle-East. Those dummies are introduced in order to control for geographical (cultural, climatic, natural, geological...) unobserved characteristics. Our results tend to confirm our insight that it captures something quite different. Indeed, the regional dummies they propose include a very large area with very different countries: South-Africa, Jordan, Tunisia and Togo (for example) seem to be sufficiently far away to not share common geographical characteristics. Since Africa is the poorest continent, we believe that the dummies capture unobserved differences strongly linked with initial development.

institutional quality, high level of investment...[25] Those common characteristics help high-income economies to compensate for the negative impact that natural resources may have on economic performance. Indeed, the probability to experience civil conflict decreases with education. Moreover, the potential cost that will be incurred in case of rebellion failure is higher in high-income economies. If market are developed, it may also reduce rebellion on grievance motives. Performing financial markets may also help to absorb shocks on resources prices. A higher (unobserved) institutional quality implies a lower corruption and misappropriation of public revenues. The dutch disease or other crowding-out mechanisms implied by natural resources are easier to fight with the appropriate economic policy if market are developed.

Since one may think that abundance generates dependence, one may want to know the net effect of natural resource abundance on economic growth. This may be done combining our IV first stage procedure. We conclude that the net effect of resource abundance is such that a one percent increase in subsoil asset generates an average increase in growth of about 0.00656 percentage point in both datasets. Nevertheless, we should be cautious in analyzing this average effect, and we believe that there is some place for a resource dependence curse. If resource abundance seems to be growth enhancing, it confirms the view that the resource curse cannot be interpreted as a low like statement: resource abundance doesn't necessarily depress growth, even if a high resource dependence tends to hamper growth in low-income economies.

25. While some of those variables may be biased through endogeneity, our approach takes the advantage to classify countries in two groups sharing common properties without any subjective choice, excepted that of the threshold variable.

3.5 Usual Tests and Robustness Check

3.5.1 Usual tests on the specification

At this point, the accuracy of our instrumental procedure inspired from Brunnschweiler & Bulte (2008) may be questioned. We thus propose to present the usual test in order to justify the choice of the model.

We decide to use a 2sls methodology while Brunnschweiler & Bulte (2008) use 3sls. A 3sls methodology provokes an efficiency gain if: *i)* residuals of different steps are correlated ; *ii)* instruments are valid and strong.

Table 3.5 – Correlation between residuals

	B&B dataset				Own dataset		
	$\hat{\varepsilon}$	$\hat{\mu}$	$\hat{v}$		$\hat{\varepsilon}$	$\hat{\mu}$	$\hat{v}$
$\hat{\varepsilon}$	1.000			$\hat{\varepsilon}$	1.000		
$\hat{\mu}$	-0.081 (0.545)	1.000		$\hat{\mu}$	0.159 (0.174)	1.000	
$\hat{v}$	0.493 (0.000)	-0.070 (0.604)	1.000	$\hat{v}$	0.471 (0.000)	-0.148 (0.206)	1.000

Notes: significance level in parenthesis

It appears from table 3.5 that for both subsamples, only $\hat{\varepsilon}$ and $\hat{v}$ are correlated. Since first stage regressions tend to show that our instruments are relatively strong, a 3sls procedure may be done. [26] Unfortunately, such a procedure is not compatible with threshold estimation since it will re-correct for endogeneity inside sub-samples. However, we can control for residuals correlations in each subsample estimating the model using a SURE methodology. This is not completely satisfactory because it does not correct for correlation residuals for the entire sample. Results on interest variables are unchanged (not reported).

26. One may nonetheless argue that the 3sls procedure is useful in the presence of stronger instruments so that it will not an improvement here.

Then, an over-identification test should be done. $Inst$ is just identified since we only use $latitude$ as an instrument. Nevertheless, we use two instruments for RD: $open$ and $pres_{70}$. We can then perform a Sargan-Hansen test of over-identifying restrictions.[27] Table 3.6 presents the results of the test: we cannot reject the null hypothesis that our instruments are uncorrelated with the error term. Validity of instruments is not rejected for our two datasets.

So far, endogeneity has been suspected in our data. Nevertheless, if the 2sls procedure has been applied while our data do not suffer from endogeneity, it implies an efficiency loss. In order to check the presence of endogeneity in our dataset, a Hausman test may be used.[28] This test can be performed using an augmented regressions. Table 3.6 reports the estimation of the coefficient $\gamma_{\hat{\mu}}$ and $\gamma_{\hat{v}}$ associated with $\hat{\mu}$ and $\hat{v}$ when introduced in (3.1).

Table 3.6 – Over-identification test and Hausman test

	B&B dataset	Own dataset
Under-identification test		
Anderson LM-stat	21.177 ($\chi^2(2)$)	16.355 ($\chi^2(2)$)
p-value	0.0000	0.0003
Over-identification test		
Sargan-Hansen J-stat	0.160 ($\chi^2(1)$)	0.023 ($\chi^2(1)$)
p-value	0.6896	0.8792
Hausman test		
$\gamma_{\hat{\mu}}$ (s.e.)	0.089* (0.047)^a	0.046 (0.045)
$\gamma_{\hat{v}}$ (s.e.)	0.001 (0.007)	0.003 (0.004)

Notes: Standard errors in parentheses.

So far instruments seem to be valid but we cannot reject strongly the null hypothesis of exogeneity.

27. See Baum *et al.* (2002) for its implementation in Stata with robust standard errors.
28. A version of the Hausman test in the presence of robust standard errors has been implemented in Stata with ivreg2. See Baum *et al.* (2002) for details.

3.5.2 The OLS regression

If data do not suffer from endogeneity, a simple ols regression is more efficient than a 2sls regression. We believe that the suspicion for endogeneity is strong and sufficient to justify a 2sls procedure. Nevertheless, a robustness check using an ols methodology seems consistent. The results of threshold tests for an uninstrumented procedure are represented on figure 3.5:

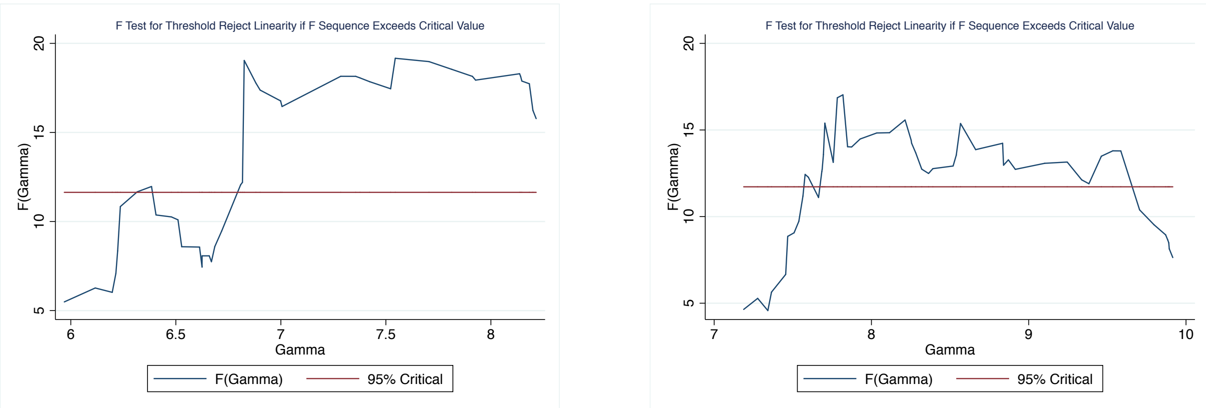

Figure 3.5 – Threshold tests: the ols case

The threshold test argues for the rejection of the null hypothesis of linearity for both datasets.Table 3.7 and 3.8 present the results of threshold estimations.

Table 3.7 – OLS regressions by subgroups: B&B dataset

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Economic growth:	All	Low	High	Low^{LB}	High^{LB}	Low^{UB}	High^{UB}
RD	-0.051**	-0.105***	0.029	0.008	-0.057**	-0.106***	0.019
	(0.024)	(0.033)	(0.019)	(0.055)	(0.022)	(0.031)	(0.017)
RA	0.004***	0.009***	-0.001	0.007**	0.002*	0.007***	-0.000
	(0.001)	(0.002)	(0.001)	(0.003)	(0.001)	(0.002)	(0.001)
$Inst$	0.018***	0.024***	0.013***	0.016	0.017***	0.023***	0.013***
	(0.003)	(0.005)	(0.003)	(0.009)	(0.003)	(0.005)	(0.003)
$gdp_{t=0}$	-0.019***	-0.026***	-0.015**	-0.056***	-0.019***	-0.023***	-0.021***
	(0.004)	(0.007)	(0.006)	(0.012)	(0.005)	(0.006)	(0.006)
$cons$	0.162***	0.189***	0.170***	0.359***	0.180***	0.176***	0.218***
	(0.025)	(0.045)	(0.044)	(0.075)	(0.032)	(0.036)	(0.046)
N	58	29	29	13	45	34	24
R^2	0.442	0.684	0.481	0.863	0.476	0.630	0.564

Notes: Standard errors in parentheses. *,** and *** refer respectively to the 10%, 5% and 1% significance levels.

Table 3.8 – OLS regressions by subgroups: Own dataset

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Economic growth:	All	Low	High	Low^{LB}	High^{LB}	Low^{UB}	High^{UB}
RD	-0.028	-0.106**	-0.002	-0.141*	-0.007	-0.106**	0.001
	(0.019)	(0.047)	(0.017)	(0.064)	(0.017)	(0.046)	(0.017)
RA	0.002***	0.003**	0.001	0.005**	0.001	0.003**	0.000
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)
$Inst$	0.012***	0.024***	0.010***	0.017	0.011***	0.024***	0.010***
	(0.002)	(0.006)	(0.002)	(0.012)	(0.002)	(0.006)	(0.002)
$gdp_{t=0}$	-0.012***	-0.016**	-0.012***	-0.034**	-0.012***	-0.016**	-0.013***
	(0.002)	(0.007)	(0.003)	(0.014)	(0.002)	(0.007)	(0.003)
$cons$	0.112***	0.142**	0.119***	0.263**	0.114***	0.142***	0.124***
	(0.017)	(0.052)	(0.024)	(0.090)	(0.020)	(0.049)	(0.023)
$Threshold$	———	7.784	7.784	7.468	7.468	7.819	7.819
N	75	27	48	16	59	28	47
R^2	0.381	0.578	0.405	0.666	0.399	0.604	0.427

Notes: Standard errors in parentheses. *,** and *** refer respectively to the 10%, 5% and 1% significance levels.

In our dataset, results confirms those previously obtained: RD has a negative impact on growth while RA is a blessing for low-income economies. There is still a catch-up effect in this group, while $Inst$ becomes significant, which seems quite obvious since OLS imply an efficiency gain with respect to IV in absence of endogeneity. Either natural resources abundance or dependence do not affect growth in developed economies.

Concerning the B&B dataset, results are similar for low-income economies. The case of high-income countries is more dubious. Indeed, the coefficient on resource dependence is strongly positive and significant. This result may be explained by endogeneity since the Hausman test presented in table 3.6 confirms that we can reject the null of exogeneity at the 5% threshold.

3.5.3 A fallacious regression ?

One may ask whether our estimation methodology is fallacious in the sense that it could amplify the small growth effect on resource dependence which has the level of development on its denominator for poorest countries. We discuss several explanation that tend to reject that view. Firstly, our sample is divided because identified subsample does not behave in the same ways with respect to natural resources, and there is no reason to obtain biased results on RD in one subsample since we propose to instrument to correct the possible endogeneity bias. Of course and as usual, some criticism may be done on the followed instrumental procedure and a bias toward OLS can never be fully rejected. Secondly, we observe in the great majority of regressions a catch-up effect: inside subsample, poorest countries have, in average, a higher growth rate, which should reduce the level of resource dependence such that the bias could go in the other way. Finally, if our threshold variable is endogenous, it should lead to a bias in the threshold estimation that may affect the results. Nevertheless, there is no *a priori* reason to believe that the estimate will be positively or negatively biased. Moreover, there is little reason to believe that this $-$ initial $-$ variable suffer from an endogeneity bias. This is confirmed by a Hausman test which compares the used specification with alternative ones where initial GDP is instrumented by its past realizations (lagged by 10 and 20 years successively). The test allows to not reject the hypotheses of exogeneity of our splitting variable.

3.5.4 Movement in resources prices

In a recent paper, James (2015) shows that the resource curse may be a "statistical mirage", mainly for two reasons. Firstly, because growth may be computed as a weighted average of growth in different sectors, resource dependence is likely to be negatively correlated with growth in periods of declining resources prices, and positively when resources prices increase. Secondly, he shows that there exists little evidence that resource dependence affects sector specific growth. This section proposes robustness check related to the first point, while the second one will be discussed afterward.

In the present work, we propose to analyze the relation between growth and natural resources for two different dataset/periods. Our first dataset is taken from Brunnschweiler & Bulte (2008). As discussed in section 3.2, we propose to do some changes in the variable choice relative to Brunnschweiler & Bulte (2008) while constructing our second dataset. Anyway, we should perform robustness check in order to assess the extent to which our results are driven by resources prices movements. Figure 3.6 shows the variation in different resources prices index. Since our works includes several mineral resources, we propose to build an index of mineral resources prices. We thus derive a weighted average of resources prices for each year where weights and series come from the World Bank commodity prices data (Pink sheet) [29]. This index also appears on figure 3.6.

29. More precisely, coefficients of 0.8297 and 0.1703 are respectively attributed for energy prices index (oil, coal, natural gas) and non-energy prices index (other non-argricultural resources)

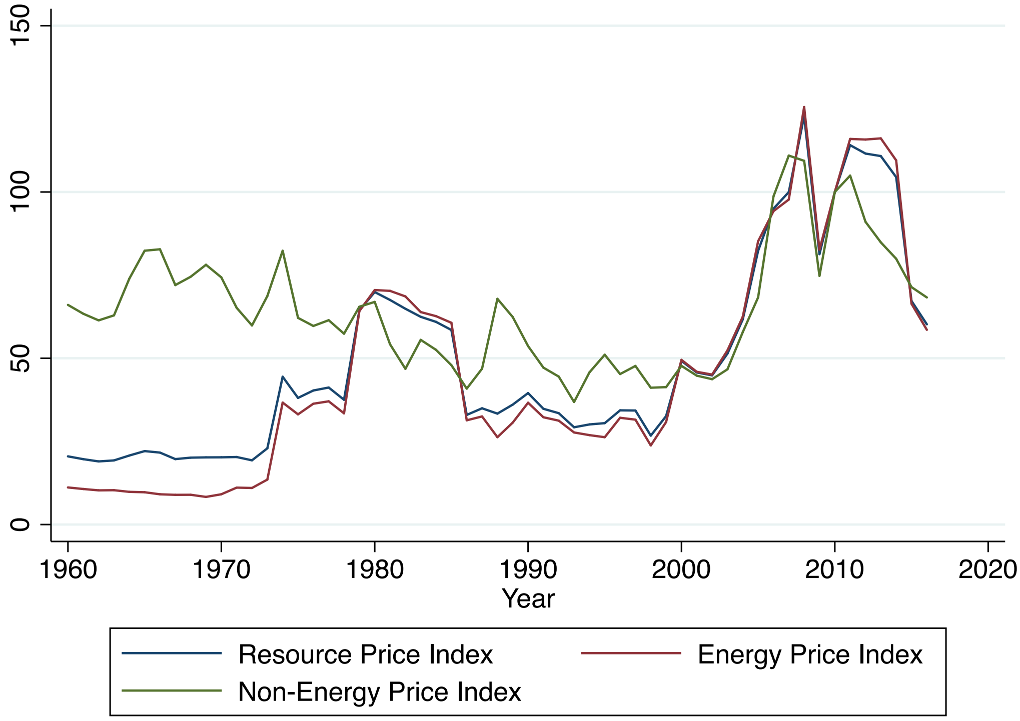

Figure 3.6 – Resource Prices

The Non-Energy Price Index reports non-energy resources prices without agricultural products. All indexes are expressed in base 100 in 2010, real 2005 US dollars.

Figure 3.6 gives a visual feeling of significant break in series. We thus propose to apply unit-root tests with structural breaks to detect the break date in resources prices. We apply the unit root test with a single change in the mean pioneered by Perron & Vogelsang (1992). [30]

The Perron & Vogelsang (1992) test with a change in the mean using the AO procedure

30. More precisely, we apply the "Additive Outlier" procedure of the test. It also exists an "Innovationnal Outlier" procedure of the test which aims at capturing incremental changes, but this procedure is best suited for large datasets.

implemented on a series y is based on the estimation of the following equation:

$$y_t = \mu + \delta \mathbb{I}_t + \widetilde{y_t}$$

where $\mathbb{I}_t = 1$ for $t > T_b$ and 0 otherwise. T_b is the date of the structural break and will be identified by the scan method. The noise from this equation is the dependent variable in the following equation:

$$\widetilde{y_t} = \sum_{i=1}^{k} \omega_i \mathbb{J}_{b,t-i} + \rho \widetilde{y_{t-1}} + \sum_{i=1}^{k} \theta_i \Delta \widetilde{y_{t-i}} + e_t$$

where $\mathbb{J}_{b,t} = 1$ for $t = T_b + 1$ and 0 otherwise. This equation is estimated for each date T_b to identify the smallest t-statistic for the unit-root hypothesis, which is then compared with the values tabulated by Perron & Vogelsang (1992). Results of the test procedure is presented on figure 3.7.

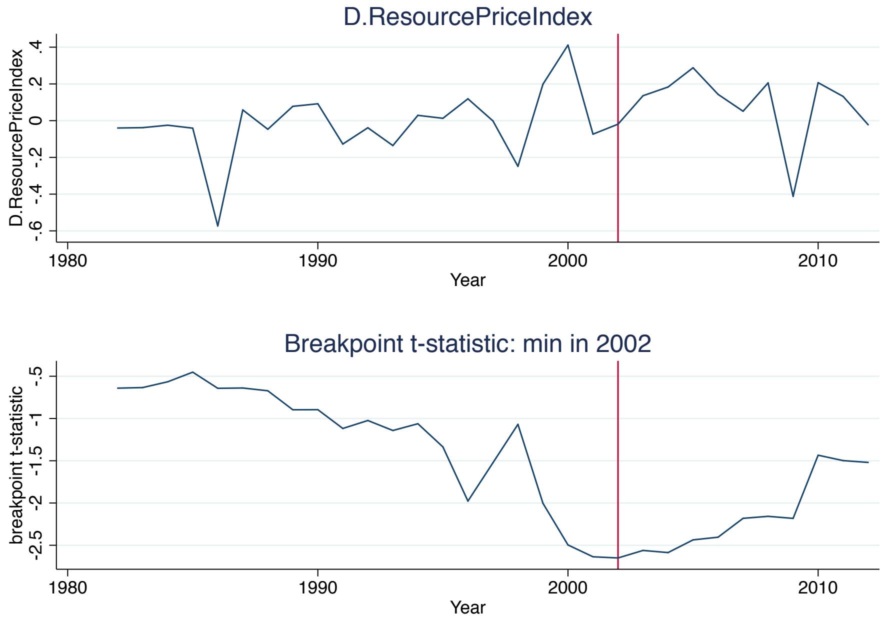

Figure 3.7 – Estimation of the break date using the Perron-Vogelsang procedure

Looking at figure 3.7, it immediately appears that the break date is estimated to be 2002. [31] This break date is consistent with what is observed in Figure 3.6 where prices begin to increase around 2002.

Table 3.9 reports OLS and IV estimates for the sub-periods identified by the Perron-Vogelsang test. The period 1980-2002, which is characterized by lower, less volatile and decreasing resources prices, exhibits estimates in line with those obtained in sections 3.4 and 3.5.2. This is particularly true for OLS regressions. In column (2), it appears that resource dependence hampers growth while resource abundance favors growth in low-income economies. Institutions also promote growth while the negative and significant coefficient on initial GDP captures a catch-up effect. This result is confirmed in column (4) where we drop from the low-income

31. Applying the Innovational Outlier procedure lead do similar result with a break date in 2001.

economies group countries that are characterized by an initial GDP that belongs to the threshold confidence interval. Column (6) includes such countries in the low-income economies group and the significance on both RD and RA is affected. Since the threshold confidence interval is quite large, this last result is not surprising. Indeed, it is likely that taking the upper bound as the threshold value leads to introduce developed countries in the low-income economies (notably, taking such a value leads to include Korea, Argentina or Brazil in the low-income economies). Concerning high-income economies, natural resources do not affect growth which is enhanced by a good institutional quality.

IV estimations lead to mitigated results for low-income economies. Notably, column (9) indicates that natural resources do not impact growth in low-income countries. Nevertheless, using instrumental variable regressions for threshold values on the bounds of the 95% confidence interval (columns 11 and 13) turn the coefficient on RD to be negative. Thus, one may be cautious while interpreting our results. Concerning high-income economies, results are equivalent to those obtained through OLS.

The 2002-2014 period exhibits different results. OLS regressions show that our model is only able to capture a catch-up effect for developed economies while a good institutional quality increases growth in low-income economies. Turning on IV regressions, there does not exist anymore a catch-up effect, while it was one of the more robust effect previously found in the chapter. We recognize that the absence of a catch-up effect over the period in our data is surprising. The sign on institutions in column (24) and (25) is also surprising. To summarize, our regressions on the 2002-2014 period do not lead to persuasive results. Those points call for a discussion. Firstly, during the period, the world economy has been affected by the subprime crisis in 2008, the stronger economic crisis since the great depression. Thus, the average growth on the period might be explained by other factor such as automatic stabilizers, the economic integration, the exposure to shocks and externally-generated crises... Secondly, the non-significance of coefficients on RD may be explained by the restricted time horizon. Indeed, our dependent variable is the average growth over the period. The average increase in resources price that occurs during the period implies an increase in both resource dependence and growth. It is thus possible that this short run price effect compensates the long run negative externality of a high resource dependence. Finally, the non significance on RA may be explained by the fact that RA is measured in 1994 and doesn't take into account discoveries that occur between 1994 and our period.

Table 3.9 – Regression on sub-periods representing different trends in resources price

1980-2002

	OLS							IV						
	Estimated threshold value: 7.703771 95% confidence interval: [7.564489-8.834043]							Estimated threshold value: 7.467742 95% confidence interval: [7.454839- 7.564489]						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	All	Low	High	Low$^{(LB)}$	High$^{(LB)}$	Low$^{(UB)}$	High$^{(UB)}$	All	Low	High	Low$^{(LB)}$	High$^{(LB)}$	Low$^{(UB)}$	High$^{(UB)}$
RD	-0.047*	-0.195***	-0.021	-0.183**	-0.025	-0.022	-0.039	-0.069	-0.599	0.018	-0.440*	0.020	-0.492*	0.018
	(0.026)	(0.064)	(0.028)	(0.077)	(0.026)	(0.038)	(0.027)	(0.062)	(0.521)	(0.056)	(0.248)	(0.056)	(0.295)	(0.057)
RA	0.002**	0.002*	0.001	0.004*	0.001	0.001	0.000	0.002*	0.013	0.000	0.006	0.001	0.008	0.000
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.016)	(0.001)	(0.006)	(0.001)	(0.006)	(0.001)
$Inst$	0.018***	0.025***	0.016***	0.022***	0.017***	0.025***	0.01 4***	0.017***	-0.013	0.021***	0.009	0.021***	0.003	0.020***
	(0.003)	(0.005)	(0.003)	(0.006)	(0.003)	(0.005)	(0.003)	(0.005)	(0.063)	(0.006)	(0.028)	(0.006)	(0.029)	(0.006)
$gdp_{t=0}$	-0.013***	-0.015*	-0.012***	-0.022*	-0.013***	-0.011**	-0.020 ***	-0.013***	-0.028	-0.015***	-0.010	-0.015***	-0.021	-0.016***
	(0.003)	(0.008)	(0.004)	(0.011)	(0.003)	(0.005)	(0.004)	(0.004)	(0.035)	(0.005)	(0.025)	(0.005)	(0.015)	(0.005)
$cons$	0.115***	0.132**	0.115***	0.174**	0.123***	0.108***	0.195 ***	0.110***	0.183	0.139***	0.085	0.139***	0.152	0.142***
	(0.021)	(0.055)	(0.033)	(0.074)	(0.028)	(0.038)	(0.040)	(0.031)	(0.200)	(0.040)	(0.162)	(0.041)	(0.102)	(0.040)
$Threshold$	——	7.703771	7.703771	7.564489	7.564489	8.834043	8.834043	——	7.467742	7.467742	7.454839	7.454839	7.564489	7.564489
N	75	25	50	19	56	45	30	75	16	59	15	60	19	56
R^2	0.483	0.709	0.429	0.687	0.453	0.482	0.740	——	——	——	——	——	——	——

2002-2014

	OLS							IV						
	Estimated threshold value: 8.165793 95% confidence interval: [8.165793 - 8.165793]							Estimated threshold value: 7.707263 95% confidence interval: [7.414891- 9.929502]						
	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)
	All	Low	High	Low$^{(LB)}$	High$^{(LB)}$	Low$^{(UB)}$	High$^{(UB)}$	All	Low	High	Low$^{(LB)}$	High$^{(LB)}$	Low$^{(UB)}$	High$^{(UB)}$
RD	0.001	0.006	0.043					-0.032	-0.055	-0.028	0.250	-0.064	-0.072	0.016
	(0.020)	(0.031)	(0.026)					(0.044)	(0.079)	(0.056)	(0.182)	(0.057)	(0.056)	(0.070)
RA	0.001	0.001	-0.001					0.001	0.003	-0.000	-0.019	0.002	0.002	0.000
	(0.001)	(0.002)	(0.001)					(0.001)	(0.003)	(0.002)	(0.014)	(0.002)	(0.002)	(0.001)
$Inst$	0.001	0.017**	0.003					-0.008	0.041*	-0.014	- 0.142	-0.011	0.000	-0.016
	(0.003)	(0.007)	(0.004)					(0.007)	(0.022)	(0.010)	(0.105)	(0.009)	(0.014)	(0.016)
$gdp_{t=0}$	-0.009***	-0.010	-0.017***					-0.002	-0.020	0.001	0.124	- 0.000	-0.004	0.021
	(0.003)	(0.008)	(0.005)					(0.006)	(0.017)	(0.010)	(0.102)	(0.008)	(0.007)	(0.022)
$cons$	0.098***	0.112*	0.182***					0.044	0.202*	0.016	-0.916	0.018	0.063	-0.191
	(0.025)	(0.055)	(0.042)					(0.046)	(0.114)	(0.084)	(0.762)	(0.068)	(0.061)	(0.215)
$Threshold$	——	8.165793	8.165793					——	7.707263	7.707263	7.290355	7.290355	9.929502	9.929502
N	75	27	48					75	20	55	10	65	53	22
R^2	0.293	0.245	0.493					——	——	——	——	——	——	——

Notes: standard errors in parenthesis. *, **, *** refer respectively to the 10%, 5%, and 1% significance levels. For each period, we report OLS and IV threshold estimates. We also reports estimates at the bound of the threshold confidence interval. Column (18)-(20) are left blank because the 95% confidence interval for ols threshold estimation on 2002-2014 period only include the threshold estimated value.

3.6 Discussion

3.6.1 A statistical mirage?

James (2015) sheds doubt on usual resource curse regressions. Indeed, numerous theories proposed by economists in order to explain the resource curse rely on a crowding-out effect mechanism. Natural resource dependence is thus assumed to slow-down growth of non-resource sectors. He develops the following argument. Consider an economy that produces two goods, a non-resource good N and a resource good R. The production Y in this economy is thus: [32]

$$Y = N + R$$

We can thus derive the growth rate G:

$$G = \frac{g^N N + g^R R}{N + R}$$

where g^N and g^R are the growth rate in non-resource and resource sectors. It thus appears that growth may be rewritten as:

$$G = g^N + (g^R - g^N)RD \tag{3.10}$$

Usually, and this work is not an exception, growth regressions estimate a variation of (3.10) where several control are introduced. Now consider, consistently with the resource curse literature, that the growth in the non-resource sector is a function of resource dependence RD with $\frac{\partial g^N(RD)}{\partial RD} < 0$. Differentiation of (3.10) with respect to RD gives:

$$\frac{\partial g^N(RD)}{\partial RD}(1 - RD) + (g^R - g^N)$$

32. Time indexes are omitted.

Thus, if non-resource growth is cursed by the resource dependence, an OLS estimation of (3.10) should lead to a coefficient on RD inferior to the difference $(g^R - g^N)$. Also, the last relation points out that the difference in estimate signs for the coefficient on RD in the literature might be explained by the relative rate of growth of resource and non-resource sectors during the observed period. James (2015) then tests his theory and shows effectively that there is little evidence that resource dependence hampers non-resource growth since there is non-significant negative difference between the coefficient he obtains while estimating variations of (3.10) and the difference in average sector growth rates.

Even if there is no crowding-out effect caused by resource dependence, and that may shed doubt on the existence of a resource curse (at least through a lot of channels), the fact that resource dependence causes a lower aggregated growth rate is still a puzzle. James & James (2011) show that this may be due to a very simple bias. Economist are often constrained by data availability, and this may create a bias while regressing growth on a set of variables among which resource dependence. Here again, consider an economy endowed with a resource and a non-resource sector. Assume that initially the income of the resource sector is zero, but that a non-renewable resource is discovered and exploited after some time. Since this resource is non-renewable, one may argue that for a constant (international) price, income from the exploitation of such a resource decreases in the long run. Figure 3.8 represents a simulation of such an economy. Immediately after the discovery the growth rate sharply decreases, and may even be negative for a huge increase in R (a big discovery). Nevertheless, the level of income which is reached each period is higher than without resources. Then, resource dependence decreases with time and the growth rate increases. Thus, if the dataset begins after $t = 5$ the regression results should be interpreted carefully, comparing the growth rates in both resource and non-resource income.

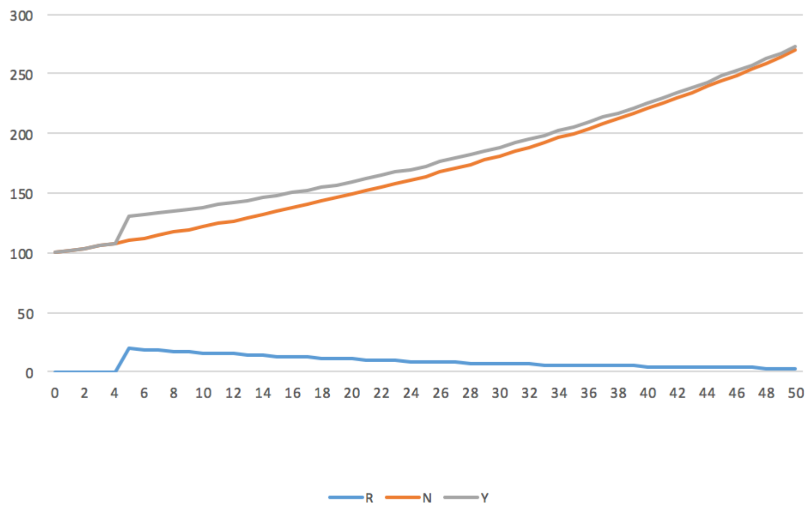

Figure 3.8 – Effect of a discovery of resource on growth
Simulation performed for average annual growth rate of 1.54% in the non-resource sector and -4% in the resource sector. Those growth rates are taken from James & James (2011) and are based on US data from 1980 to 2000.

In the chapter, our estimations report cross-country results and the previous discussion shows that they should be interpreted carefully since discoveries does not occur in the same time. Resource dependent economies might be economies where the discovery occurs closer in time, which probably explains lower growth rates. From that point of view, research using time series seems complementary to the present work. This suggestion is aslo supported by the next section which deals with cross-sectional heterogeneity.

3.6.2 Some examples illustrating cross-sectional heterogeneity

This chapter uses the Hansen (2000) sample splitting methodology in order to use regressions techniques on homogeneous subsamples. However, there may be still cross-sectional heterogeneity among our subsamples. If we find that there may be a resource curse for less developed economies, its mechanisms may be different between countries. Moreover, some countries ranked as high-income economies by our methodology may suffer from a resource curse. The present section is dedicated to the analyses of this issue.

The low-income countries, according to the Hansen's sample splitting methodology, are in fact characterized by different experiences with respect to natural resources as shown in table 3.10.

Table 3.10 – Resource abundance and resource dependence in the low-income subsample

Country	RA	RD
Bangladesh	3.044523	0.120%
Burundi	0	0.296%
China	6.042633	1.248%
Egypt	5.802118	4.973%
Haiti	0	0.004%
India	5.351858	1.314%
Mozambique	0	11.217%
Nepal	2.397895	0.178%
Niger	0	10.028%
Rwanda	0	1.876%
Senegal	4.110874	4.329%
Sierra Leone	4.795791	11.819%
Togo	4.795791	7.837%
Uganda	0	0.343%
Viet Nam	4.26268	9.747%
Zambia	5.888878	22.461%

Note : Resource abundance is the log of subsoil asset measured in 1994. Resource dependence is the mineral exportation to GDP ratio averaged over the period (Source: World Bank).

Our subsample includes different countries with different experiences with natural resources. For example, Sierra Leone is abundant in diamonds, Zambia is one of the world biggest copper producer, Nepal is resource-poor. From our data, Uganda aslo appears as resource poor. Nevertheless, it has been classified as a "prospectively" resource-rich country by IMF because of recent oil discoveries. Niger has a resource abundance of 0 but 10.028% of its GDP over the period comes from mineral exports, mainly uranium. Niger thus appears resource dependent but not resource abundant because uranium is not included in the RA index. Mozambique also appears as resource dependent but has an abundance index of 0 because RA is measured in 1994 while Mozambique began to seriously exploit its deposits at the end of the 90s. Moreover, the estimation of future rent by the World Bank could not take into account the surge in resources price that occurs in 2000s. This surge is however accounted for in RD. China and India, two fast-growing countries during the 1980-2014 period but classified in the low-income level in 1980, are not resource dependent. This heterogeneity confirms the fact that cross-country regressions should be interpreted carefully while used for investigate the resource curse.

Moreover, differences in resources experiences does not rely only on differences in RA and/or RD. One may want to discuss why some other countries are negatively impacted by resource dependence. We thus propose to briefly discuss two country cases, Zambia and Sierra Leone, that highlight the differences in resource experiences.

Blood diamonds in Sierra Leone

Since their discovery in the 1930s, diamonds play a major role in explaining the development path followed by Sierra Leone. Between the 1930s and the 1970s, diamonds were the engine of the economy. Indeed, one quarter of GDP could be attributed to diamonds while they accounted for more than 65% of exports earning (Temple, 2006). In 1968, President Siaka Stevens came to power and appointed his relatives to important positions. Then, revenues from diamonds exploitation was dedicated to support his clan, reducing the diamond industry to a smuggled and corrupted para-public industry (Maconachie & Binns, 2007). This has led to the establishment of an excluded poor class, one of the probable cause of the 1990s war. While the war causes are plural, it has been well established that the Sierra Leone war was diamond-fueled (Keen, 2005; Smillie *et al.* , 2000). [33] Two popular explanations are often debated considering the Sierra Leone case. The greed theory suggests that the main objective of rebels is to capture a

33. This is not specific to Sierra Leone, Angola and Democratic Republic of Congo are other popular examples of diamond-fueled conflicts.

share of the resource rent while the grievance theory argues that the motivation of rebels is social justice.[34] Moreover, diamond may cause a longer war since warring parties find some funding with diamonds. While it makes no doubt that diamonds are a major determinant of Sierra Leone war that occurs between March 1991 and January 2002 and its duration, there exists some evidences that diamonds promotes development in the prewar period. Indeed, there exist field studies which show that farmer may produce large quantities of food crops to supply on the mining area market and reinvest benefits in homes and in the expansion of cash crops (Binns, 1982; Rosen, 1974). Maconachie & Binns (2007) show that the link between diamond mining and farming has been maintained after the war, in spite of dislocation during the war. In order to turn the curse into a blessing Sierra Leone has been involved into two initiatives. Firstly, the Kimberley Process Certification Scheme is a certification scheme involving around 50 diamond producer countries which aims at removing conflicts rough diamonds from the global supply chain.[35] Secondly, the Diamond Area Community Development Fund has been implemented in 2001. The fund objective is to provide incentive for diamonds miners and chiefdoms to be involve in legal activities. Broadly speaking, the fund returns to chiefdoms a share of diamond exports tax revenues proportional to legal production. The received amount must be invested in local development project. While those initiatives exhibit some limitations,[36] they mark the Sierra Leone willingness to monitor diamond exploitation, to avoid diamond-fueled conflicts, and to use diamond revenues to rebuild the country. In all cases, those initiatives may explain an important share of Sierra Leone development performance with an HDI increasing from 0.344 in 2005 to 0.413 en 2014.

34. The interested reader should refer to Collier (2000).

35. According to the Kimberley Process website, the participants should "satisfy 'minimum requirements' and establish national legislation, institutions and import/export controls, commit to transparent practices and to the exchange of critical statistical data, trade only with fellow members who also satisfy the fundamentals of the agreement, certify shipments as conflict-free and provide the supporting certification".

36. See Maconachie & Binns (2007).

Copper price volatility, enclave industry and mismanagement of resource revenues in Zambia

The Zambian economy has been cursed by resource dependence through different channels.[37] Maybe the most important one is copper price volatility. Zambia supply its copper at prices based on the London Metal Exchange, which is subject to extreme fluctuations. After its independence, president Kaunda has nationalized mining societies to create a giant conglomerate: the Zambia Consolidated Copper Mines. He decides to nationalize mining companies in 1969, because of the failure of them to invest in the Zambian economy. According to firms, they cannot invest in the Zambian economy because of the dissuasive royalty taxation system. More reasonably, we can argue that the low level of investment from mining companies is due to the characteristics of the industry. Indeed, copper mining is an “enclave” industry that requires very specialized inputs, a lot of capital, and few labor. Thus, spin-off effects of the copper industry tends to be limited. After the nationalization, Zambia benefits from copper revenues to begin import-substitution policies and agricultural subsidies following recommendation of the United Nations Economic Commission for Africa. However, this policy showed its limitations when the copper price began to fall in the 1970s. Public expenditures stayed high in order to maintain social progresses that had been achieved although public revenues diminished: the Zambian public debt has exploded. Then, the Zambian government faced two different pressures. While trade unions defended benefits and subsidies, declining terms of trade and the debt crisis constrained Zambia to consider IMF and World Bank structural adjustments program. If the country engaged with reforms hesitantly in the 1980s, it follows IMF recommendations in the 1990s, cutting wages and subsidies. The privatization process of the mining industry begin in 1997. Because the privatization was done when the price of copper hits new record lows, the sale revenues where lower than expected. Unfortunately for Zambia, some companies that had bought the mines pulled out two years later. For example, Anglo American departure was seen

37. For more details on the Zambian curse, the interested reader could refer to Fraser & Larmer (2010). Crain (2010) proposes an interesting comparison of Bostwana and Zambia.

as “the biggest failure of privatization in Africa thus far” (Nevin, 2002). In 2004, an unexpected copper price boom occurs and mining companies became profitable, but those companies took advantage of the weakening of trade unions that occurred. They keep wages and employment low, and they do not invest in the Zambian economy. While it has lead to mining nationalization in the 1969s, the erosion of state power and the actual ideological context was different in the 2000s. Liberalization laws had withdrawn preexisting states control on the mining industries. Notably, the market regime that appears established that mining companies and the government should work together: mining firms should invest in regional development while the government should keep low resource taxation and few regulation on labor, health and environment to promote such an investment. In addition, tax revenues should be used to build road, and to provide social services as health and education. In fact the Zambian state was so engaged in securing investment that the effective tax rate was close to 0. Actually, expected benefits of privatization didn’t occurs. New investors used inputs from outside Zambia and local production of such inputs collapse. Moreover, as shown by Haglund (2010), investor benefits from weak Zambian institutions to ignore laws with impunity. This has led the government of Mwanawasa to impose a new tax regime in January 2008, demonstrating that “African governments and parliaments ultimately retain some autonomy of action, some legalistic sovereignty” (Fraser, 2010). However, a large part of this new tax regime was abandoned because of pressure from companies. To conclude, it seems that investment from the firms begin to increase thanks to the Chinese company (NFC Mining Africa Plc). If this company was known to be one of the worst investor in Zambia, it seems that it turned to be more socially responsible since late 2000s. According to Lee (2010), this is mainly due to a parastatal financement scheme which provides flexible loans. Thus, the company is not forced to leave in the case of a temporary diminution of copper price as Western companies used to do.

To summarize, the enclave characteristics of the copper industry implies few spin-off effect. The falling copper price that occurs after nationalization lead Zambia to an extreme indebtedness. It has lead to a strong liberalization of the economy, and specifically of the mining industry. Finally, the weakness of the state which is partially constraint by the IMF structural adjustments program, causes its inability to levy resource taxes to promote development. Recently, a new fall in copper prices has demonstrated that the history seems repeat itself. In 2015, Zambia has thus known an economic crisis due to the decrease in copper demand from China that put the copper price at its lower level for 7 years.

The two examples of Zambia and Sierra Leone show the diversity of phenomenon that resource-rich countries may experience. Notably, they allow to contrast our previous results and they give incentive to pursue research on the resource curse issue using time series data or comparative studies. At least, they call for some caution while interpreting cross country growth regressions dealing with the resource curse.

3.7 Conclusion

This chapter amends the work of Brunnschweiler & Bulte (2008) in order to improve the way they consider heterogeneities between countries. Notably, it uses the sample splitting methodology proposed by Hansen (2000) on the same dataset. One of their main result is affected: resource dependence negatively affects development for low-income economies (but still has no effect in high-income economies). We recognize that this result is not independent with the choice of the threshold variable. While our method allows to test for and to estimate the value of the threshold without any subjective consideration, economists still have to choose the threshold variable. Initial GDP is highly correlated with human capital, current trade openness, markets development,... We believe that high-income economies share common properties that allow them to limit the negative influence that natural resources may have on growth. Thus, we argue that developing education, financial markets and institutions may allow to limits the bad influence that dependence may have on growth. Moreover, since dependence is the outcome of economic choices, it could be avoided with an appropriate diversifying policy.

To summarize, this chapter highlights that one cannot infer universal law like statement that natural resources abundance is a blessing or a curse. We argue that while, in average, resource abundance seems to favor growth in low-income economies, there exists some place for a resource dependence curse. Nevertheless, the reader should keep in mind some limits inherent to cross countries growth regressions dealing with the resource curse.

Since we cannot infer universal law like statement on the existence of the resource curse and on its transmission channels, we think that further research on this issue should rely on time series, case studies, or comparative studies which may help to deal with the great diversity of resource experiences, as illustrated by the Zambian and Sierra Leonean examples.

Appendices

A.31 Data sources

The following table describes data sources for each variable:

Table 11 – Sources of variables

Source	Variables	Dataset
Penn World Table 6.1	$Growth$	B&B
	$open$	B&B
	$gdp_{t=0}$	B&B
Penn World Table 9.0	$Growth$	Own
	$open$	Own
	$gdp_{t=0}$	Own
World Development Indicators, The World Bank	RD	Both
The World Bank (1997)	RA	Both
Kaufmann *et al.* (2004)	$Inst$	Both
Beck *et al.* (2001) and Persson & Tabellini (2004)	Both $pres_{t=0}$	Both
La Porta *et al.* (1999)	$latitude$	Both

We would like to thank Christa N. Brunnschweiler and Erwin H. Bulte to provide their entire dataset on Christa Brunnschweiler's personal website.

A.32 List of countries

Table 12 – List of countries: B&B dataset

Argentina	Australia	Austria	Bangladesh
Belgium	Benin	Bolivia	Brazil
Cameroon	Canada	China	Colombia
Congo Rep. Of	Cote d'Ivoire	Denmark	Dominican Republic
Ecuador	Egypt	Finland	France
Ghana	Greece	Guatemala	Honduras
India	Indonesia	Ireland	Italy
Jamaica	Japan	Jordan	Korea
Malaysia	Mexico	Morocco	Nepal
Netherlands	New Zealand	Norway	Pakistan
Peru	Philippines	Portugal	Senegal
Sierra Leone	South Africa	Spain	Sweden
Thailand	Togo	Trinidad and Tobago	Tunisia
Turkey	United Kingdom	United States	Venezuela
Zambia	Zimbabwe		

Table 13 – List of countries: Own dataset

Argentina	Australia	Austria	Bangladesh
Belgium	Benin	Bolivia	Botswana*
Brazil	Burundi*	Cameroon	Canada
Chile*	China	Colombia	Congo Rep. Of
Côte d'Ivoire	Denmark	Dominican Republic	Ecuador
Egypt	Finland	France	Germany*
Ghana	Greece	Guatemala	Haiti*
Honduras	India	Indonesia	Ireland
Italy	Jamaica	Japan	Jordan
Kenya*	Korea	Malaysia	Mauritania*
Mexico	Morocco	Mozambique*	Nepal
Netherlands	New Zealand	Nicaragua*	Niger*
Norway	Pakistan	Peru	Philippines
Portugal	Rwanda*	Saudi Arabia*	Senegal
Sierra Leone	Spain	South Africa	Sri Lanka*
Sweden	Switzerland*	Tanzania*	Thailand
Togo	Trinidad and Tobago	Tunisia	Turkey
Uganda*	United Kingdom	United States	Venezuela
Viet Nam*	Zambia	Zimbabwe	

Note: countries marked with a star are not in the B&B dataset. All other countries are common to both dataset.

A.33 Results from Clootens and Kirat (2017)

This section reproduces result obtained in Clootens & Kirat (2017). In this note, we use Brunnschweiler & Bulte (2008)'s dataset and methodology we and test its robustness to the omission of regional dummies (table 14). Then we take into account heterogeneity that may exist between OECD (northern) and non-OECD (southern) countries estimating separately the model on both subsamples (table 15).

Table 14 – Regressions with and without dummies

	With Dummies	Without Dummies
Economic Growth: $Growth$		
RD	-4.625 (3.130)	-9.996*** (3.604)
RA	0.345*** (0.127)	0.503*** (0.135)
$Inst$	1.666* (0.918)	1.596*** (0.498)
$gdp_{t=0}$	-2.073*** (0.804)	-1.806*** (0.511)
$afme$	-1.673*** (0.645)	
$eurca$	0.132 (1.142)	
aoc	-0.205 (1.156)	
nam	-0.433 (1.366)	
$cons$	14.400*** (3.807)	11.656*** (2.249)
Resource Dependence: RD		
$pres_{t=0}$	0.035 (0.022)	0.017 (0.021)
RA	0.016*** (0.005)	0.016*** (0.004)
$Inst$	-0.027 (0.017)	-0.027** (0.011)
$open$	0.259*** (0.040)	0.222*** (0.034)
$afme$	-0.011 (0.024)	
$eurca$	0.021 (0.039)	
aoc	0.035 (0.029)	
nam	0.030 (0.056)	
$cons$	-0.095* (0.055)	-0.063 (0.047)
Institutions: $Inst$		
$latitude$	2.920*** (0.585)	4.334*** (0.365)
RA	0.104*** (0.039)	0.088** (0.039)
$afme$	0.105 (0.201)	
$eurca$	0.870*** (0.302)	
aoc	0.591*** (0.214)	
nam	0.879** (0.440)	
$cons$	0.983*** (0.310)	1.056*** (0.254)
Observations	58	58

Notes: Robust standard errors in parentheses. *,** and *** refer respectively to the 10%, 5% and 1% significance levels.

Table 15 – Regressions by subgroups

	Northern vs Southern		OECD vs non-OECD	
	Northern	Southern	OECD	non-OECD
Economic Growth: $Growth$				
RD	6.784 (8.549)	-10.724*** (4.073)	-3.207 (10.908)	-10.529*** (3.528)
RA	0.054 (0.087)	0.739*** (0.181)	0.025 (0.108)	0.939*** (0.185)
$Inst$	0.313 (0.660)	1.479** (0.723)	1.303* (0.716)	1.229 (0.955)
$gdp_{t=0}$	-1.585** (0.674)	-2.048*** (0.600)	-2.623*** (0.753)	-2.149*** (0.501)
$cons$	17.519*** (3.325)	12.207*** (2.548)	22.288*** (3.242)	12.225*** (2.567)
Resource Dependence: RD				
$pres_{t=0}$	-0.002 (0.011)	0.024 (0.029)	-0.005 (0.010)	0.025 (0.036)
RA	0.006** (0.003)	0.019*** (0.006)	0.007*** (0.002)	0.024*** (0.007)
$Inst$	0.002 (0.012)	-0.029 (0.023)	-0.006 (0.010)	-0.070 (0.056)
$open$	0.082*** (0.024)	0.265*** (0.046)	0.082*** (0.021)	0.265*** (0.049)
$cons$	-0.055 (0.041)	-0.096 (0.079)	-0.022 (0.036)	-0.037 (0.145)
Institutions: $Inst$				
$latitude$	3.814*** (0.952)	3.476*** (0.734)	3.257*** (0.830)	1.503** (0.660)
RA	0.036 (0.054)	0.100** (0.049)	0.056 (0.054)	0.058 (0.042)
$cons$	1.774*** (0.527)	1.115*** (0.343)	2.012*** (0.532)	1.608*** (0.292)
N	17	41	22	36

Notes: Standard errors in parentheses. *,** and *** refer respectively to the 10%, 5% and 1% significance levels.

A.34 Ranking of countries according to their initial GDP

Table 16 – Countries initial GDP (B&B dataset)

Country	$GDP_{t=0}$	Country	$GDP_{t=0}$
China	5.493062	Guatemala	6.881329
Nepal	5.502849	Jamaica	6.901425
Indonesia	5.518416	Turkey	6.998711
India	5.774893	Brazil	7.005608
Bangladesh	5.797637	Peru	7.284999
Benin	5.884964	Trinidad and Tobago	7.356248
Congo Rep. Of	5.958321	Venezuela	7.376827
Pakistan	5.969142	Mexico	7.422523
Sierra Leone	6.116378	Portugal	7.522541
Cameroon	6.197299	South Africa	7.544629
Togo	6.214708	Ireland	7.705159
Senegal	6.223072	Greece	7.813434
Ghana	6.23588	Spain	7.911866
Honduras	6.316172	Argentina	7.927007
Jordan	6.384317	Italy	8.136574
Thailand	6.405691	Austria	8.141568
Morocco	6.479078	Finland	8.147182
Egypt	6.510333	Japan	8.182883
Dominican Republic	6.528031	United Kingdom	8.199832
Philippines	6.612847	Belgium	8.215321
Ecuador	6.624782	France	8.23327
Zimbabwe	6.625061	Norway	8.253959
Bolivia	6.659127	New Zealand	8.295261
Korea	6.669447	Netherlands	8.306786
Tunisia	6.685511	Canada	8.323276
Malaysia	6.718663	Australia	8.407646
Cote d'Ivoire	6.808509	Sweden	8.434876
Colombia	6.817185	Denmark	8.472905
Zambia	6.825666	United States	8.517247

Table 17 – Countries initial GDP (Own dataset)

Country	$\text{GDP}_{t=0}$	Country	$\text{GDP}_{t=0}$
Mozambique	6.272926	Jordan	8.319818
Nepal	6.598667	Tunisia	8.363196
Uganda	6.598799	Argentina	8.390453
Burundi	6.644112	Nicaragua	8.519217
Viet Nam	6.94202	Brazil	8.539363
Rwanda	6.997822	Republic of Korea	8.566487
Sierra Leone	7.039226	Ecuador	8.662552
India	7.060626	Chile	8.834044
Bangladesh	7.102811	Colombia	8.839992
Egypt	7.138162	Malaysia	8.870657
Niger	7.187807	Turkey	8.914726
Zambia	7.276714	South Africa	9.101506
Senegal	7.341405	Portugal	9.244714
China	7.364484	Venezuela	9.337077
Togo	7.454839	Mexico	9.382741
Haiti	7.467742	Ireland	9.46186
Tanzania	7.508167	Greece	9.534591
Benin	7.538316	Spain	9.585358
Cameroon	7.564489	New Zealand	9.704974
Kenya	7.578335	Austria	9.796559
Pakistan	7.598724	Finland	9.870296
Sri Lanka	7.663667	Japan	9.883867
Botswana	7.684616	United Kingdom	9.890353
Ghana	7.686902	Germany	9.893573
Bolivia	7.694797	Italy	9.915998
Mauritania	7.703772	Sweden	9.916651
Indonesia	7.757038	Trinidad and Tobago	9.957191
Côte d'Ivoire	7.783038	Denmark	9.973353
Zimbabwe	7.818669	Belgium	9.988627
Congo	7.84828	France	10.01429
Morocco	7.873981	Australia	10.0233
Honduras	7.928187	Netherlands	10.08931
Philippines	8.033772	Canada	10.13983
Thailand	8.114961	Norway	10.20454
Guatemala	8.213802	United States	10.2826
Dominican Republic	8.252292	Switzerland	10.36542
Peru	8.25546	Saudi Arabia	10.8151
Jamaica	8.281657		

A.35 First stages regressions

Table 18 and 19 presents first stage regressions of the instrumental procedure.

Table 18 – First stages regressions : Own dataset

	All	Low	High
Mineral Dependence: RD			
RA	0.016*** (0.005)	0.022** (0.009)	0.011* (0.006)
$gdp_{t=0}$	-0.009 (0.014)	-0.048 (0.036)	0.020 (0.030)
$pres_{t=0}$	0.025 (0.020)	0.044 (0.032)	-0.001 (0.029)
$latitude$	-0.077 (0.065)	0.054 (0.118)	-0.225** (0.089)
$open$	0.223*** (0.036)	0.286*** (0.074)	0.213*** (0.046)
$cons$	-0.056 (0.086)	0.093 (0.217)	-0.170 (0.212)
R^2	0.588	0.565	0.699
$F\ stat$	14.83	5.97	10.68
Institutions: $Inst$			
RA	-0.009 (0.036)	-0.004 (0.062)	-0.010 (0.038)
$gdp_{t=0}$	0.530*** (0.102)	0.611** (0.260)	1.075*** (0.194)
$pres_{t=0}$	-0.351** (0.147)	-0.380* (0.220)	-0.215 (0.188)
$latitude$	2.202*** (0.463)	1.399 (0.819)	1.822*** (0.575)
$open$	-0.012 (0.260)	-0.608 (0.511)	0.323 (0.299)
$cons$	-3.776*** (0.615)	-3.829** (1.500)	-8.144*** (1.366)
R^2	0.840	0.373	0.897
$F\ stat$	54.72	2.74	40.11
N	58	29	29

Notes: Standard errors in parentheses. *,** and *** refer respectively to the 10%, 5% and 1% significance levels.

Table 19 – First stages regressions : Own dataset

	All	Low	High
Mineral Dependence: RD			
RA	0.012*** (0.003)	0.008 (0.006)	0.015*** (0.001)
$gdp_{t=0}$	0.015 (0.010)	-0.009 (0.042)	0.028** (0.016)
$pres_{t=0}$	0.030 (0.019)	0.025 (0.054)	0.028 (0.024)
$latitude$	-0.210*** (0.052)	-0.083 (0.133)	-0.281*** (0.70)
$open$	0.107*** (0.030)	0.197** (0.065)	0.134*** (0.039)
$cons$	-0.130 (0.078)	0.047 (0.285)	-0.249** (0.125)
R^2	0.475	0.615	0.512
$F\ stat$	12.47	3.20	11.12
Institutions: $Inst$			
RA	0.007 (0.025)	0.095 (0.053)	-0.043 (0.031)
$gdp_{t=0}$	0.309*** (0.081)	-0.370 (0.323)	0.404*** (0.115)
$pres_{t=0}$	-0.507*** (0.153)	-0.497 (0.418)	-0.359** (0.174)
$latitude$	2.472*** (0.420)	0.237 (1.026)	2.591*** (0.519)
$open$	0.039 (0.240)	-0.132 (0.505)	0.224 (0.287)
$cons$	-2.858*** (0.637)	2.118 (2.202)	-3.740*** (0.926)
R^2	0.804	0.466	0.797
$F\ stat$	56.64	1.75	41.68
N	75	16	59

Notes: Standard errors in parentheses. *,** and *** refer respectively to the 10%, 5% and 1% significance levels.

Conclusion

Environnement et développement interagissent au travers de relations complexes. Chacun des trois chapitres développés dans cette thèse a été écrit avec la volonté d'essayer d'améliorer la connaissance des différentes dimensions de ces interactions. Ce faisant, des pistes de réflexion sur des politiques économiques qui pourraient à la fois favoriser le développement économique tout en préservant la qualité de l'environnement et les ressources sont envisagées. En outre, chaque chapitre ouvre des perspectives pour de nouvelles recherches.

Le chapitre premier utilise un modèle à générations imbriquées prenant en compte une double causalité entre qualité de l'environnement et espérance de vie des agents. Il montre qu'au travers d'effets sur l'espérance de vie, une augmentation de la pollution vient réduire l'épargne et affecte les possibilités de développement. Ce chapitre démontre également l'existence de trappes à pauvreté environnementales. L'environnement pourrait donc être vu comme une limite à la croissance. Cette limite peut cependant être surmontée, malgré une contrainte de stabilisation des finances publiques, par la mise en place de politiques environnementales appropriées. Des échanges dette-contre-nature peuvent permettre de sortir de la trappe, en favorisant la qualité de l'environnement et en stimulant l'investissement. Par ailleurs, l'intérêt d'une politique environnementale volontaire, consistant à augmenter la maintenance publique, est démontré. Celle-ci favorise à la fois l'environnement et le développement.
Ce chapitre ouvre des perspectives de recherches dont deux retiendrons particulièrement notre attention. Premièrement, il pourrait être intéressant d'endogénéiser l'espérance de vie qui de-

vrait alors dépendre certes de la qualité de l'environnement, mais aussi des niveaux de revenu et de capital humain. Une autre piste de recherche consisterait à supprimer la contrainte de stabilisation des finances publiques. La dette publique pourrait alors être vue comme un mode de financement de la dépense environnementale, et pourrait alors avoir des effets positifs sur le revenu. On pourrait alors analyser les ajustements dynamiques suivant un choc sur la dépense environnementale selon qu'elle soit financée par l'impôt ou par la dette.

Dans le second chapitre, un modèle introduisant des ressources non-renouvelables polluantes est développé. Dans la lignée des travaux néoclassiques, les limites imposées à la croissance par le caractère fini des ressources peuvent être dépassées à l'aide du progrès technique et de la substitution capital/ressource, si tant est que cette dernière puisse se faire à un rythme suffisamment élevé. Nous analysons également les effets des pollutions non persistantes résultant de l'extraction et/ou de l'utilisation de ressources sur la soutenabilité (faible) de l'économie. Plus spécifiquement, nous montrons que ces pollutions pourraient ne pas être un obstacle à la soutenabilité malgré leurs effets négatifs sur la productivité globale des facteurs, car elles limitent l'utilisation de ressources et augmentent la probabilité d'atteindre un sentier de consommation non-décroissant. Une autre contribution importante de ce chapitre est de donner des pistes pouvant aider à atteindre l'optimum social. Nous nous attardons plus spécifiquement sur deux alternatives. La première consiste à instaurer une taxe sur l'utilisation des ressources dont le niveau sera calibré de sorte à ramener l'utilisation des ressources à son niveau optimal. La seconde consiste à confier la gestion des ressources à un fond dont la politique d'extraction est dictée par une règle consistant à extraire la ressource au taux optimal, ce dernier ne dépendant que du taux d'actualisation social. La taxe sera plus facile à implémenter si les droits de propriété sur les ressources sont définis de manière privée. Si les droits de propriété sont publics, la mise en place d'un fond semble être une bonne alternative.
Ce chapitre ouvre lui aussi des perspectives de recherches. Premièrement, on pourrait s'interroger sur la robustesse des résultats si la pollution affectait aussi l'espérance de vie des agents, donc l'accumulation du capital par le canal de l'épargne. Deuxièmement, introduire la pollution

comme un stock devant rester sous un seuil permettrait d'analyser d'autres dynamiques comme celles liées à la lutte contre le changement climatique. Troisièmement, si nous avons proposé deux alternatives permettant de décentraliser le taux de croissance optimal sur le sentier de croissance équilibré, il n'est pas certain que ces deux alternatives mènent aux mêmes résultats sur la dynamique de transition. L'une des stratégies pourrait alors dominer l'autre.

Enfin, le troisième chapitre étudie la malédiction des ressources sous un angle empirique. Nous reprenons à ce titre un travail important mené par Brunnschweiler & Bulte (2008) et nous corrigeons la façon dont ils prennent en compte l'hétérogénéité entre les pays, en classant les pays selon leur niveau de développement initial en deux catégories définies de manière endogène. Nous montrons que les pays sélectionnés comme étant à hauts revenus ne semblent pas être impactés par les ressources naturelles tandis que les pays à bas revenus semblent être négativement affectés par la dépendance aux ressources naturelles et positivement par leur abondance. Les ressources naturelles ne peuvent dès lors pas être vues comme une limite à la croissance, puisque leur abondance favorise cette dernière. Les effets négatifs de la dépendance peuvent alors être surmontés par des politiques de diversification de l'économie consistant à réinvestir la rente issue de leur exploitation dans les secteurs secondaire et tertiaire. Par ailleurs, nous suggérons que les pays développés partagent des caractéristiques communes (capital humain élevé, forte ouverture commerciale, marchés financiers développés...) leur permettant de limiter l'impact que les ressources naturelles peuvent avoir sur la croissance. Développer ces caractéristiques pourraient permettre aux pays en développement de limiter l'impact négatif de la dépendance sur leur économie.

Identifier plus précisément ces caractéristiques communes aux pays développés leur permettant de limiter l'impact des ressources sur leur économie pourrait être une piste de recherche future intéressante. Une autre piste intéressante serait d'approfondir la question des interdépendances entre la malédiction des ressources et le niveau de développement initial, mais en se basant cette fois-ci sur la dimension temporelle des données.

Bibliographie

Acemoglu, Daron, Johnson, Simon, & Robinson, James A. 2001. The Colonial Origins of Comparative Development : An Empirical Investigation. *American Economic Review*, 1369–1401.

Agnani, Betty, Gutiérrez, María-José, & Iza, Amaia. 2005. Growth in overlapping generation economies with non-renewable resources. *Journal of Environmental Economics and Management*, **50**(2), 387–407.

Altonji, Joseph G, Hayashi, Fumio, & Kotlikoff, Laurence J. 1992. Is the extended family altruistically linked ? Direct tests using micro data. *The American Economic Review*, 1177–1198.

Arrow, Kenneth, Bolin, Bert, Costanza, Robert, Dasgupta, Partha, Folke, Carl, Holling, Crawford S, Jansson, Bengt-Owe, Levin, Simon, Mäler, Karl-Göran, Perrings, Charles, *et al.* . 1995. Economic growth, carrying capacity, and the environment. *Ecological economics*, **15**(2), 91–95.

Atkinson, Giles, & Hamilton, Kirk. 2003. Savings, growth and the resource curse hypothesis. *World Development*, **31**(11), 1793–1807.

Babu, P Guruswamy, Kumar, KS Kavi, & Murthy, NS. 1997. An overlapping generations model with exhaustible resources and stock pollution. *Ecological Economics*, **21**(1), 35–43.

Baum, Christopher F, Schaffer, Mark E, & Stillman, Steven. 2002. *IVREG2 : Stata module for extended instrumental variables/2SLS and GMM estimation*. Statistical Software Components, Boston College Department of Economics.

Beck, Thorsten, Clarke, George, Groff, Alberto, Keefer, Philip, & Walsh, Patrick. 2001. New tools in comparative political economy : The database of political institutions. *The World Bank Economic Review*, **15**(1), 165–176.

Beckerman, Wilfred. 1992. Economic growth and the environment : Whose growth ? Whose environment ? *World Development*, **20**(4), 481–496.

Binns, JA. 1982. *The changing impact of diamond mining in Sierra Leone*. University of Sussex.

Blanchard, Olivier J. 1984. Debt, deficits and finite horizons.

Bohn, Henning, & Deacon, Robert T. 2000. Ownership risk, investment, and the use of natural resources. *American Economic Review*, 526–549.

Bomsel, Olivier. 1992. The political economy of rent in mining countries. *Mineral Wealth and Economic Development*, 59–79.

Brunnschweiler, Christa N, & Bulte, Erwin H. 2008. The resource curse revisited and revised : A tale of paradoxes and red herrings. *Journal of Environmental Economics and Management*, **55**(3), 248–264.

Bruno, Michael, & Sachs, Jeffrey. 1982. Energy and resource allocation : A dynamic model of the "Dutch Disease". *The Review of Economic Studies*, **49**(5), 845–859.

Budina, Mrs Nina, Kinda, Mr Tidiane, Schaechter, Ms Andrea, & Weber, Anke. 2012. *Fiscal rules at a glance : country details from a new dataset*. International Monetary Fund.

Caner, Mehmet, & Hansen, Bruce E. 2004. Instrumental variable estimation of a threshold model. *Econometric Theory*, **20**(05), 813–843.

Cassimon, Danny, Prowse, Martin, & Essers, Dennis. 2011. The pitfalls and potential of debt-for-nature swaps : A US-Indonesian case study. *Global Environmental Change*, **21**(1), 93–102.

Chakraborty, Shankha. 2004. Endogenous lifetime and economic growth. *Journal of Economic Theory*, **116**(1), 119–137.

Clootens, Nicolas. 2017. Public Debt, Life Expectancy, and the Environment. *Environmental Modeling & Assessment*, **22**(3), 267–278.

Clootens, Nicolas, & Kirat, Djamel. 2017. A Reappraisal of the Resource Curse. *Economics Bulletin*, **37**(1), 12–18.

Collier, Paul. 2000. *Economic causes of civil conflict and their implications for policy*. The World Bank, Washington.

Conrad, Jon M. 2010. *Resource Economics*. Cambridge university press.

Copeland, Brian R, & Taylor, M Scott. 1995. Trade and the environment : a partial synthesis. *American Journal of Agricultural Economics*, **77**(3), 765–771.

Corden, Warner Max. 1984. Booming sector and Dutch disease economics : survey and consolidation. *Oxford Economic Papers*, 359–380.

Crain, Audria. 2010. *The resource curse : The cases of Botswana and Zambia*. University of Denver.

Crosby, A.W. 2004. *Ecological Imperialism : The Biological Expansion of Europe, 900-1900*. Studies in Environment and History. Cambridge University Press.

Daniel, Philip. 1992. Economic policy in mineral-exporting countries : what have we learned ? *Mineral Wealth and Economic Development*, 81–121.

Dasgupta, Partha, & Heal, Geoffrey. 1974. The optimal depletion of exhaustible resources. *The Review of Economic Studies*, 3–28.

Dasgupta, Partha S, & Heal, Geoffrey Martin. 1979. *Economic theory and exhaustible resources*. Cambridge University Press.

Dasgupta, Susmita, Laplante, Benoit, Wang, Hua, & Wheeler, David. 2002. Confronting the environmental Kuznets curve. *The Journal of Economic Perspectives*, **16**(1), 147–168.

Davis, Graham A, & Tilton, John E. 2005. The resource curse. *Pages 233–242 of : Natural Resources Forum*, vol. 29. Wiley Online Library.

De La Croix, David, & Michel, Philippe. 2002. *A theory of economic growth : dynamics and policy in overlapping generations*. Cambridge University Press.

Deacon, Robert T, & Murphy, Paul. 1997. The structure of an environmental transaction : the debt-for-nature swap. *Land Economics*, 1–24.

Diamond, Peter A. 1965. National debt in a neoclassical growth model. *The American Economic Review*, 1126–1150.

Dinda, Soumyananda. 2004. Environmental Kuznets curve hypothesis : a survey. *Ecological Economics*, **49**(4), 431–455.

Durlauf, Steven N, & Johnson, Paul A. 1995. Multiple regimes and cross-country growth behaviour. *Journal of Applied Econometrics*, **10**(4), 365–384.

Escolano, Mr Julio. 2010. *A practical guide to public debt dynamics, fiscal sustainability, and cyclical adjustment of budgetary aggregates*. International Monetary Fund.

Feenstra, Robert C, Inklaar, Robert, & Timmer, Marcel P. 2015. The next generation of the Penn World Table. *The American Economic Review*, **105**(10), 3150–3182.

Fodha, Mouez, & Seegmuller, Thomas. 2012. A note on environmental policy and public debt stabilization. *Macroeconomic Dynamics*, **16**(03), 477–492.

Fodha, Mouez, & Seegmuller, Thomas. 2014. Environmental quality, public debt and economic development. *Environmental and Resource Economics*, **57**(4), 487–504.

Frankel, Jeffrey A, & Romer, David. 1999. Does trade cause growth ? *American Economic Review*, 379–399.

Fraser, Alastair. 2010. Introduction : Boom and Bust on the Zambia Copperbelt. *Pages 1–30 of : Zambia, Mining, and Neoliberalism*. Springer.

Fraser, Alastair, & Larmer, Miles. 2010. *Zambia, mining, and neoliberalism : boom and bust on the globalized Copperbelt*. Springer.

Gerlagh, Reyer, & Keyzer, Michiel A. 2001. Sustainability and the intergenerational distribution of natural resource entitlements. *Journal of Public Economics*, **79**(2), 315–341.

Glaeser, Edward L, La Porta, Rafael, Lopez-de Silanes, Florencio, & Shleifer, Andrei. 2004. Do institutions cause growth ? *Journal of Economic Growth*, **9**(3), 271–303.

Gradus, Raymond, & Smulders, Sjak. 1993. The trade-off between environmental care and long-term growth—pollution in three prototype growth models. *Journal of Economics*, **58**(1), 25–51.

Grossman, Gene M, & Krueger, Alan B. 1991. *Environmental impacts of a North American free trade agreement*. Tech. rept. National Bureau of Economic Research.

Grossman, Gene M, & Krueger, Alan B. 1994. *Economic growth and the environment*. Tech. rept. National Bureau of Economic Research.

Gylfason, Thorvaldur. 2001. Natural resources, education, and economic development. *European economic review*, **45**(4), 847–859.

Haber, Stephen, & Menaldo, Victor. 2011. Do natural resources fuel authoritarianism ? A reappraisal of the resource curse. *American Political Science Review*, **105**(01), 1–26.

Haglund, Dan. 2010. From boom to bust : Diversity and regulation in Zambia's privatized copper sector. *Pages 91–126 of : Zambia, Mining, and Neoliberalism*. Springer.

Hall, Robert E, & Jones, Charles I. 1999. Why Do Some Countries Produce So Much More Output Per Worker Than Others ? *The Quarterly Journal of Economics*, **114**(1), 83–116.

Hansen, Bruce E. 2000. Sample splitting and threshold estimation. *Econometrica*, **68**(3), 575–603.

Hansen, Stein. 1989. Debt for nature swaps – overview and discussion of key issues. *Ecological Economics*, **1**(1), 77–93.

Hart, Jaime E, Garshick, Eric, Dockery, Douglas W, Smith, Thomas J, Ryan, Louise, & Laden, Francine. 2011. Long-term ambient multipollutant exposures and mortality. *American Journal of Respiratory and Critical Care Medicine*, **183**(1), 73–78.

Höök, Mikael, & Aleklett, Kjell. 2009. Historical trends in American coal production and a possible future outlook. *International Journal of Coal Geology*, **78**(3), 201–216.

Hsu, Angel, Emerson, Jay, Levy, M, de Sherbinin, Alex, Johnson, Laura, Malik, Omar, Schwartz, J, & Jaiteh, Malanding. 2014. The 2014 environmental performance index. *New Haven, CT : Yale Center for Environmental Law and Policy*, 4701–4735.

Hübler, Michael, Klepper, Gernot, & Peterson, Sonja. 2008. Costs of climate change : the effects of rising temperatures on health and productivity in Germany. *Ecological Economics*, **68**(1), 381–393.

Humphreys, Macartan, Sachs, Jeffrey, & Stiglitz, Joseph E. 2007. *Escaping the resource curse*. Columbia University Press.

IMF. 2014. *World Economic Outlook Database*.

Jacobsson, Fredric, Johannesson, Magnus, & Borgquist, Lars. 2007. Is altruism paternalistic ? *The Economic Journal*, **117**(520), 761–781.

James, Alexander. 2015. The resource curse : A statistical mirage ? *Journal of Development Economics*, **114**, 55–63.

James, Alexander G, & James, Robert G. 2011. Do resource dependent regions grow slower than they should ? *Economics Letters*, **111**(3), 194–196.

John, Andrew, & Pecchenino, Rowena. 1994. An overlapping generations model of growth and the environment. *The Economic Journal*, 1393–1410.

John, Andrew, Pecchenino, Rowena, Schimmelpfennig, David, & Schreft, Stacey. 1995. Short-lived agents and the long-lived environment. *Journal of Public Economics*, **58**(1), 127–141.

Jouvet, Pierre-André, Pestieau, Pierre, & Ponthiere, Gregory. 2010. Longevity and environmental quality in an OLG model. *Journal of Economics*, **100**(3), 191–216.

Karl, Terry Lynn. 1999. The perils of the petro-state : reflections on the paradox of plenty. *Journal of International Affairs*, 31–48.

Kaufmann, Daniel, Kraay, Aart, Mastruzzi, Massimo, *et al.* . 2004. Governance matters III : Governance indicators for 1996, 1998, 2000, and 2002. *The World Bank Economic Review*, **18**(2), 253–287.

Keen, David. 2005. *Conflict and collusion in Sierra Leone*. James Currey (imprint of Boydell & Brewer Ltd.).

Konte, Maty. 2013. A curse or a blessing ? Natural resources in a multiple growth regimes analysis. *Applied Economics*, **45**(26), 3760–3769.

Krugman, Paul. 1987. The narrow moving band, the Dutch disease, and the competitive consequences of Mrs. Thatcher : Notes on trade in the presence of dynamic scale economies. *Journal of Development Economics*, **27**(1), 41–55.

La Porta, Rafael, Lopez-de Silanes, Florencio, Shleifer, Andrei, & Vishny, Robert. 1999. The quality of government. *Journal of Law, Economics, and Organization*, **15**(1), 222–279.

Laden, Francine, Schwartz, Joel, Speizer, Frank E, & Dockery, Douglas W. 2006. Reduction in fine particulate air pollution and mortality : extended follow-up of the Harvard Six Cities study. *American Journal of Respiratory and Critical Care Medicine*, **173**(6), 667–672.

Lazo, Jeffrey K, McClelland, Gary H, & Schulze, William D. 1997. Economic theory and psychology of non-use values. *Land Economics*, 358–371.

Lee, Ching Kwan. 2010. Raw Encounters : Chinese Managers, African Workers, and the Politics of Casualization in Africa's Chinese Enclaves. *Pages 127–153 of :* Fraser, Alastair, & Larmer, Miles (eds), *Zambia, Mining, and Neoliberalism*. New York : Palgrave Macmillan US.

Maconachie, Roy, & Binns, Tony. 2007. Beyond the resource curse ? Diamond mining, development and post-conflict reconstruction in Sierra Leone. *Resources Policy*, **32**(3), 104–115.

Mariani, Fabio, Pérez-Barahona, Agustin, & Raffin, Natacha. 2010. Life expectancy and the environment. *Journal of Economic Dynamics and Control*, **34**(4), 798–815.

Matsen, Egil, & Torvik, Ragnar. 2005. Optimal Dutch Disease. *Journal of Development Economics*, **78**(2), 494–515.

McConnell, Kenneth E. 1997. Does altruism undermine existence value ? *Journal of Environmental Economics and Management*, **32**(1), 22–37.

Meadows, Donella H, Meadows, Dennis L, Randers, Jorgen, & Behrens, Williams W. 1972. The limits to growth. *New York*, **102**.

Minea, Alexandru, & Villieu, P. 2010. Dette publique, croissance et bien-être : une perspective de long terme. *Economie et Prévision*, **10**(1-2), 33–55.

Minea, Alexandru, & Villieu, Patrick. 2013. Debt policy rule, productive government spending, and multiple growth paths : A note. *Macroeconomic Dynamics*, **17**(04), 947–954.

Nevin, Tom. 2002. 'Think again, Anglo,'says Anderson Mazoka. *African Business*.

Nielsen, Søren Bo, Pedersen, Lars Haagen, & Sørensen, Peter Birch. 1995. Environmental policy, pollution, unemployment, and endogenous growth. *International Tax and Public Finance*, **2**(2), 185–205.

Ono, Tetsuo, & Maeda, Yasuo. 2001. Is aging harmful to the environment ? *Environmental and Resource Economics*, **20**(2), 113–127.

Ono, Tetsuo, & Maeda, Yasuo. 2002. Sustainable development in an aging economy. *Environment and Development Economics*, **7**(01), 9–22.

Papyrakis, Elissaios, & Gerlagh, Reyer. 2004. The resource curse hypothesis and its transmission channels. *Journal of Comparative Economics*, **32**(1), 181–193.

Perron, Pierre, & Vogelsang, Timothy J. 1992. Nonstationarity and level shifts with an application to purchasing power parity. *Journal of Business & Economic Statistics*, **10**(3), 301–320.

Persson, Torsten, & Tabellini, Guido. 2004. Constitutional rules and fiscal policy outcomes. *The American Economic Review*, **94**(1), 25–45.

Pigou, Arthur C. 1932. The Economics of Welfare, 1920. *McMillan&Co., London*.

Ramsey, Frank Plumpton. 1928. A mathematical theory of saving. *The Economic Journal*, 543–559.

Rhee, Changyong. 1991. Dynamic inefficiency in an economy with land. *The Review of Economic Studies*, **58**(4), 791–797.

Rodríguez, María Xosé Vázquez, & León, Carmelo J. 2004. Altruism and the economic values of environmental and social policies. *Environmental and Resource Economics*, **28**(2), 233–249.

Rodrik, Dani, Subramanian, Arvind, & Trebbi, Francesco. 2004. Institutions rule : the primacy of institutions over geography and integration in economic development. *Journal of Economic Growth*, **9**(2), 131–165.

Rosen, DM. 1974. *The Kono of Sierra Leone—a study of social change*. Tech. rept. Mimeo Paper to Kono Road Project, Fourah Bay College, Freetown.

Ross, Michael L. 1999. The political economy of the resource curse. *World Politics*, **51**(02), 297–322.

Sachs, Jeffrey D, & Warner, Andrew M. 1995. *Natural resource abundance and economic growth*. Tech. rept. National Bureau of Economic Research.

Sachs, Jeffrey D, & Warner, Andrew M. 1999. The big push, natural resource booms and growth. *Journal of development economics*, **59**(1), 43–76.

Sachs, Jeffrey D, & Warner, Andrew M. 2001. The curse of natural resources. *European Economic Review*, **45**(4), 827–838.

Sala-i Martin, Xavier, & Subramanian, Arvind. 2008. Addressing the natural resource curse : An illustration from Nigeria. *Pages 61–92 of : Economic Policy Options for a Prosperous Nigeria*. Springer.

Samuelson, Paul A. 1958. An exact consumption-loan model of interest with or without the social contrivance of money. *The Journal of Political Economy*, 467–482.

Schou, Poul. 2000. Polluting non-renewable resources and growth. *Environmental and Resource Economics*, **16**(2), 211–227.

Schou, Poul. 2002. When environmental policy is superfluous : growth and polluting resources. *The Scandinavian Journal of Economics*, **104**(4), 605–620.

Smillie, Ian, Gberie, Lansana, Hazleton, Ralph, *et al.* . 2000. *The Heart of the Matter : Sierra Leone Diamonds and Human Security*. Partnership Africa Canada Ottawa.

Smith, James L. 2013. Issues in extractive resource taxation : A review of research methods and models. *Resources Policy*, **38**(3), 320–331.

Solow, Robert M. 1974. Intergenerational equity and exhaustible resources. *The review of economic studies*, 29–45.

Solow, Robert M. 1986. On the intergenerational allocation of natural resources. *The Scandinavian Journal of Economics*, 141–149.

Stern, Nicholas H, Peters, Siobhan, Bakhshi, Vicki, Bowen, Alex, Cameron, Catherine, Catovsky, Sebastian, Crane, Di, Cruickshank, Sophie, Dietz, Simon, Edmonson, Nicola, *et al.* . 2006. *Stern Review : The economics of climate change*. Vol. 30. Cambridge University Press Cambridge.

Stiglitz, Joseph. 1974. Growth with exhaustible natural resources : efficient and optimal growth paths. *The review of economic studies*, 123–137.

Temple, H. 2006. Livelihoods report. *Report prepared for DfID, Freetown. London : DfID*.

The World Bank. 1997. *Expanding the measure of wealth : indicators of environmentally sustainable development*. World Bank.

Torvik, Ragnar. 2001. Learning by doing and the Dutch disease. *European Economic Review*, **45**(2), 285–306.

Van der Ploeg, Frederick. 2011. Natural resources : Curse or blessing ? *Journal of Economic Literature*, 366–420.

Van der Ploeg, Frederick, & Poelhekke, Steven. 2009. Volatility and the natural resource curse. *Oxford Economic Papers*, gpp027.

Van der Ploeg, Frederick, & Poelhekke, Steven. 2010. The pungent smell of “red herrings” : Subsoil assets, rents, volatility and the resource curse. *Journal of Environmental Economics and Management*, **60**(1), 44–55.

Withagen, Cees. 1994. Pollution and exhaustibility of fossil fuels. *Resource and Energy Economics*, **16**(3), 235 – 242.

Zivin, Joshua Graff, & Neidell, Matthew. 2012. The Impact of Pollution on Worker Productivity. *The American Economic Review*, **102**(7), 3652–3673.

Nicolas CLOOTENS

Trois Essais sur les Relations de Long Terme entre Croissance et Environnement

Résumé :
Environnement et activités humaines interagissent à travers des relations multiples et complexes. Cette thèse s'interroge sur les limites que l'environnement pourrait imposer à la croissance. Le premier chapitre montre que l'environnement peut constituer un frein au développement en diminuant l'espérance de vie des agents, en freinant leur épargne, et peut causer des situations de trappes à pauvreté environnementales. La mise en place de politiques environnementales publiques peut néanmoins permettre d'éviter ces trappes et d'augmenter le niveau de revenu par tête. Dans le second chapitre, l'existence de ressources non-renouvelables polluantes nécessaires à la production est susceptible de freiner la croissance. Cependant, dans la lignée des travaux néoclassiques des années 70, les difficultés liées au caractère fini des ressources peuvent être dépassées par un progrès technologique exogène et des possibilités de substitution capital-ressources suffisantes. Il est par ailleurs démontré qu'une pollution non-persistante provenant de l'utilisation des ressources ne constituait pas un frein au développement. Enfin, le troisième chapitre démontre qu'une forte dépendance aux ressources naturelles affecte négativement la croissance des pays en développement, tandis que l'abondance en ressources naturelles la favorise. La dépendance étant le résultat de choix économiques, une politique de diversification de l'économie consistant à réinvestir les rentes issues de l'exploitation des ressources naturelles dans les secteurs secondaire et tertiaire pourrait permettre de la réduire. Par ailleurs, nous suggérons que développer l'éducation, les institutions et les marchés financiers pourrait permettre de limiter le risque de malédiction des ressources.

Mots clés : Croissance, Environnement, Ressources, Pollution, Générations Imbriquées, Malédiction des Ressources.

Three Essays on Long Run Interactions between Growth and the Environment

Abstract :
Human activities and the environment interact through multiple and complex relations. Can the natural environment be viewed as a limit to growth ? This thesis tries to develop answers to this crucial question. The first chapter shows that environmental degradations may constitute a brake on growth diminishing life expectancy, and thus savings. It also shows that environmental poverty traps may exist. However, public environmental policies may help countries to escape from such traps, and to reach a higher level of income per capita. In the second chapter, we suggest that the existence of polluting non-renewable resources necessary for production may hamper growth. However, we show that flow pollutions caused by the use of resources can't be seen as a development brake. Then, following neoclassical works of the 1970s, we confirm that exogenous technological progress and sufficient substitution possibilities may allow to overcome difficulties linked to the exhaustibility of resources. Finally, the third chapter demonstrates that, in low-income economies, strong resource dependency dampens growth while abundance is growth promoting. Dependence is the outcome of economic choices. Thus a diversification policy that consists on investing the rent in secondary and tertiary sectors may help reduce dependence. Finally, we suggest that the development of education, institutions, and financial markets may allow to decrease the probability to experience a resource curse.

Keywords : Growth, Environment, Natural Resources, Overlapping Generations, Resource Curse.

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