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Yassine Kirat

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UNIVERSITÉ PARIS 1 PANTHÉON - SORBONNE  
U.F.R. DES SCIENCES ÉCONOMIQUES  
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**Economic and environmental impacts of natural resources  
abundance**

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Yassine Kirat

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# Introduction

## Long Résumé en français

Le processus d'industrialisation, qui a commencé au Royaume-Uni au milieu du XVIIIe siècle, a transformé à jamais les nations. Le développement d'une société moderne de production et de consommation n'a été possible que grâce à la révolution industrielle, qui a rendu l'accès à la nourriture et aux vêtements accessible à tous. Les Britanniques ont réussi deux grandes révolutions, la révolution agricole et la révolution industrielle. Le passage de l'agriculture à l'industrie a augmenté le taux d'emploi en Angleterre grâce à de nouveaux emplois dans ce secteur. Les moteurs à vapeur ont également commencé à être utilisés dans l'industrie, d'abord à base de bois, puis de charbon. L'utilisation du charbon a été un facteur déterminant du succès de la révolution industrielle (Behringer, 2010). En 1750, la production annuelle de charbon était d'environ 5,2 millions de tonnes par an en Angleterre ; en 1870, elle a atteint 100 millions de tonnes par an - vingt fois plus qu'en 1750 (Behringer, 2010). Cette augmentation considérable de l'extraction du charbon participe au développement d'industries tels que le textile, le fer et les produits chimiques. Entre 1870 et 1910, la construction ferroviaire atteint son apogée grâce à l'utilisation du charbon comme principale source d'approvisionnement des réseaux ferroviaires en Angleterre. L'utilisation du charbon pour alimenter les machines à vapeur et la production textile mécanisée s'est répandue de l'Angleterre vers l'Europe continentale, l'Amérique du Nord et le Japon (Behringer, 2010).

Le pétrole était le deuxième combustible fossile le plus important après le charbon lors de la première révolution industrielle. Cependant, l'invention des véhicules à essence en 1878 contribué sur le long terme à faire du pétrole la principale source d'énergie fossile. En 1908, la production automobile à grande échelle connaît un nouveau succès avec la fameuse voiture Model T d'Henry Ford (Behringer, 2010). Ce seul modèle a été vendu à plus de 15 millions d'exemplaires, ce qui a conduit les États-Unis à devenir le plus grand consommateur de pétrole en 1927 (Behringer, 2010). Après la Seconde Guerre mondiale, le pétrole a remplacé le charbon dans les années 1950



parce qu'il était moins cher à produire et moins polluant. Les combustibles fossiles, du charbon au pétrole, ont contribué au succès du processus d'industrialisation. Ils ont permis à une urbanisation à grande échelle, à des innovations technologiques, à la libéralisation du commerce, l'accumulation de richesses, des emplois mieux rémunérés et à de meilleurs niveaux de vie.

Aujourd'hui, des niveaux de croissance économique plus élevés sont atteints grâce à une exploitation intensive des ressources naturelles et à une production industrielle accrue. Il en résulte des taux plus élevés de consommation d'énergie et une demande mondiale d'énergie qui devrait augmenter dans les décennies à venir (croissance démographique, industrialisation et modernisation des processus, urbanisation et électrification). Selon le Conseil mondial de l'énergie (CME) et l'Agence internationale de l'énergie (AIE), cette dernière devrait augmenter de 40% d'ici 2035 et doubler d'ici 2050. Au moins 80% de l'augmentation devrait provenir des pays en voie de développement et émergents. Par conséquent, l'approvisionnement en énergie, essentiel à la croissance économique et au développement social, est généralement un enjeu pour les économistes. Surtout dans les pays et les régions où l'énergie a toujours été rare, et donc coûteuse.

Intuitivement, un pays disposant d'une abondance de ressources naturelles devrait afficher des niveaux élevés de croissance et vice-versa (Canuto and Cavallari, 2012). Selon Emtage et al. (2007), les ressources naturelles, une fois découvertes, attirent les capitaux et la main-d'œuvre pour l'extraction, la transformation, la vente et le transport des matières premières. Des entreprises sont créées pour extraire, raffiner et transporter les ressources naturelles afin d'en tirer profit. D'autres industries se développent et participent à ces processus en améliorant les possibilités d'emploi et la génération de revenus. Les gouvernements perçoivent des impôts qui peuvent être dépensés pour améliorer l'infrastructure physique et sociale et le capital humain. Ces découvertes minérales ont parfois joué un rôle moteur dans la transformation de petits villages en grandes villes, comme ce fut le cas à Johannesburg et Los Angeles à la suite de leurs ruées respectives vers l'or et le pétrole (Petterson, 1951). Il semble alors raisonnable de penser que la croissance économique devrait être alimentée par les ressources naturelles. Les facteurs de production (travail et capital) augmentent fortement à la suite de la découverte des ressources naturelles, ce qui entraîne une augmentation de la production et une croissance de l'économie.

Il est néanmoins frappant de constater que les pays pauvres en ressources naturelles surpassent les pays riches en ressources naturelles. Sachs and Warner (1995) soulignent que cette situation se répète régulièrement. Ils notent qu'au XVIIIe siècle, malgré l'afflux de ressources en provenance de ses colonies, l'Espagne a été dépassée économiquement par les Pays-Bas, pays pauvre en ressources.

Plus récemment, les Dragons asiatiques (Corée, Taiwan, Hong Kong, Singapour), qui sont pauvres en ressources, ont connu une industrialisation rapide de leur économie, tandis que de nombreuses économies riches en ressources comme le Mexique, le Nigeria et le Venezuela, ont fait "faillite" (Sachs and Warner, 2001). Ainsi, contre-intuitivement, la dotation en ressources naturelles est devenue une caractéristique des régions et des pays qui ont connu une faible croissance économique. Selon Sachs and Warner (2001), ces régions et pays souffriraient de la malédiction des ressources naturelles.

De plus, l'utilisation des ressources naturelles n'est pas sans effets négatifs. Au cours des dernières décennies, l'augmentation rapide des émissions anthropiques de gaz à effet de serre est principalement due à la ruée vers de meilleurs niveaux de vie. L'industrialisation favorise la croissance économique et le niveau de vie, mais elle s'accompagne d'une pollution accrue qui menace notre mode de vie. La mauvaise qualité de l'air, la hausse des températures de la mer, les ouragans plus violents, les conditions météorologiques extrêmes, les sécheresses prolongées, les pénuries de nourriture et d'eau, les migrations forcées et l'extinction des espèces sont des menaces réelles. Par rapport à l'époque pré-industrielle, les niveaux de CO<sub>2</sub> ont augmenté de plus de 40%. Selon un rapport du Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC) de 2014, cette hausse est principalement due à l'industrialisation et à la combustion de combustibles fossiles. Les émissions anthropiques mondiales ont continué d'augmenter au cours du XXI<sup>e</sup> siècle, avec une augmentation significative entre 2000 et 2010, par rapport à toute autre décennie. Le même rapport souligne que les émissions mondiales de gaz à effet de serre ont augmenté de 31% en 2010 par rapport à 1990. La température moyenne combinée de la surface terrestre et océanique de la planète au cours du XXI<sup>e</sup> siècle a augmenté de 0,85 Celsius, et la couverture neigeuse a diminué de 1,6% par décennie. On prévoit que la température moyenne mondiale continuera d'augmenter, avec la fonte des neiges et des glaces et l'élévation du niveau de la mer au XXI<sup>e</sup> siècle.

Ces impacts négatifs sur l'environnement ont attiré beaucoup d'attention dans le monde entier. L'augmentation de la température mondiale observée au cours des décennies précédentes est principalement due aux niveaux plus élevés de dioxyde de carbone (CO<sub>2</sub>), de méthane (CH<sub>4</sub>) et d'oxyde nitreux (N<sub>2</sub>O) dans l'atmosphère. La plupart des climatologues estiment que l'environnement se détériore rapidement en raison du changement climatique. Le changement climatique est principalement dû à l'activité humaine, et non à des événements qui se produisent naturellement. Les climatologues montrent que l'augmentation de l'activité industrielle affecte le niveau de vie et la croissance économique à long terme dans le monde entier. Plus précisément, il est prouvé qu'une mauvaise qualité de l'air a une incidence directe sur la durée de vie humaine. Watt et al. (2008) montrent que les effets chroniques sur la santé et la spécificité des causes de décès sont liés à

l'exposition aux particules fines (PM<sub>2,5</sub>), d'après des données sur 22 902 sujets des cohortes de l'American Cancer Society. Aunan and Pan (2004) confirment également l'impact sérieux de la mauvaise qualité de l'air sur la morbidité et la mortalité humaines. Au fur et à mesure que ces questions sont portées à l'attention du public, la sensibilisation à l'environnement augmente. Ces défis ont également attiré l'attention des chercheurs en économie, en sociologie et dans d'autres domaines intéressés par l'identification des déterminants des polluants et à comprendre comment la société peut prendre des mesures pour réduire ces effets individuellement ou collectivement.

Dans ce contexte où les ressources naturelles peuvent être à la fois un moteur de croissance et une menace en soi, cette thèse contribue au débat sur l'utilisation des ressources naturelles dans ses dimensions économique et environnementale. Elle se divise en quatre parties : une introduction générale et trois chapitres principaux qui traitent distinctement de différents aspects liés à l'utilisation des ressources naturelles. Plus précisément, deux chapitres portent sur le lien entre les ressources naturelles et la croissance économique et un chapitre sur la relation entre les ressources naturelles et l'environnement.

Le premier chapitre est intitulé "The actual impact of shale gas revolution on the U.S. manufacturing sector". Il traite de l'un des faits les plus marquants de l'histoire de l'énergie en ce début du XXI<sup>e</sup> siècle, l'extraction du gaz naturel des formations de schistes argileux aux États-Unis. Il a pour objectif de contribuer au débat sur l'opportunité d'exploiter les ressources fossiles non conventionnelles en identifiant et en évaluant l'impact de l'extraction massive du gaz de schiste sur le secteur manufacturier américain.

Le deuxième chapitre, co-écrit avec Mireille-Chiroleu-Assouline et Mouez Fodha, s'intitule "Carbon Curse in Developed Countries". Dans ce chapitre nous étudions la relation entre les ressources naturelles et les émissions de CO<sub>2</sub> et traitons de façon détaillée deux questions. La première cherche à savoir si un pays riche en ressources naturelles est plus polluant qu'un autre pays moins riche en ressources naturelles. La seconde est celle du périmètre d'impact de l'abondance des ressources naturelles sur les émissions de CO<sub>2</sub> des différents secteurs d'une économie. Elle cherche à déterminer dans quelle mesure l'abondance en ressources naturelles affecte les émissions de CO<sub>2</sub> de tous les secteurs de l'économie. Ce chapitre a pour ambition de contribuer au débat sur la lutte contre le changement climatique en mesurant les conséquences de l'abondance des ressources naturelles sur les émissions CO<sub>2</sub> à différents niveaux : national et sectoriel.

Le troisième et dernier chapitre s'intitule "Revisiting the resource curse: does volatility matters?". Ce chapitre revisite l'hypothèse de la malédiction des ressources dans un contexte particulier. En

effet, la plupart des études portant sur le paradoxe de la " malédiction des ressources " examinent les effets négatifs sur la croissance de l'abondance et/ ou de la dépendance des matières premières en négligeant généralement, à quelques exceptions près, l'impact du canal de la volatilité. Par conséquent, ce chapitre se fixe pour objectif principal de déterminer si l'abondance des ressources naturelles en soi est une malédiction ou si les effets négatifs observés sur la croissance pourraient être dus à la volatilité des revenus tirés des ressources naturelles. En outre, il contribue à la littérature en examinant les canaux par lesquels l'effet de la volatilité opère, notamment l'investissement, le capital humain et la qualité institutionnelle. Cela est particulièrement important pour les pays où les énergies fossiles sont abondantes et pour lesquels les revenus des ressources naturelles sont très volatils.

Dans ce qui suit, nous présentons d'abord un aperçu général du contenu de la thèse. Ensuite, nous présentons les principales contributions de cette thèse de doctorat en résumant l'objectif, la méthodologie et les résultats de chacun de ses chapitres.

## **Ressources naturelles et développement économique**

Les ressources naturelles sont essentielles au fonctionnement des sociétés et des économies. En tant qu'input indispensable à la plupart des processus de production, elles constituent une matière première et fournissent de l'énergie pour le transport, la lumière et la chaleur dans le monde entier. Toutefois, les ressources naturelles sont inégalement réparties entre les pays. Par conséquent, elles font l'objet d'échanges commerciaux intensifs et peuvent fortement influencer la spécialisation industrielle d'un pays (Bacchetta et al., 2010). La gestion des ressources naturelles a un impact significatif sur le développement industriel dans les domaines de la production des ressources et sur la possibilité de progresser vers la durabilité.

Depuis la Seconde Guerre mondiale, le développement économique des pays de l'OCDE a été fondé sur le recours au pétrole comme principale source d'énergie, se substituant au charbon. Tout au long des années 1950 et 1960, le développement économique fulgurant qui a été enregistré dans la plupart des pays industrialisés reposait, entre autres, sur un accès à du pétrole abondant et bon marché. Dans les années 1960, la création de l'Organisation des pays exportateurs de pétrole (OPEP) a été le reflet de l'évolution de l'équilibre du rapport de force entre les compagnies pétrolières occidentales et les pays producteurs de pétrole, qui a abouti au premier choc pétrolier, en 1973. Cette première crise pétrolière a définitivement mis fin aux trente Glorieuses et bouleversa les théories économiques keynésiennes en déclenchant le phénomène de stagflation (faible croissance

et forte inflation, accompagnées d'un taux de chômage élevé)(Antonin, 2013) .

La crise pétrolière de 1973 a marqué le début d'une nouvelle ère. Une ère de prix du pétrole élevés et volatils, qui sera marquée par d'autres chocs pétroliers, dont le plus récent remonte à l'an 2000. Avant cette crise, on s'inquiétait de plus en plus des limites futures de la croissance en raison, entre autres, de la rareté des ressources naturelles (Meadows et al., 1972). En réponse aux préoccupations croissantes concernant les ressources limitées, l'insécurité énergétique et la croissance restreinte, on a assisté au cours des deux dernières décennies à une expansion significative du développement des ressources alternatives, dites ressources non conventionnelles. La situation a peut-être changé puisque de nombreux pays industrialisés peuvent avoir accès à des ressources fossiles non conventionnelles, ce qui pourrait sécuriser leur approvisionnement énergétique et réduirait leur facture énergétique. Les premiers à lancer ce processus sont les États-Unis, pionniers dans ce domaine. C'est ainsi que le premier chapitre de cette analyse l'impact de l'émergence de ressources non conventionnelles sur l'activité économique américaine.

## **La révolution du gaz de schiste aux Etats-Unis**

### **Qu'est ce que c'est que le gaz de schiste et d'où vient-il ?**

Le gaz naturel contenu dans les réservoirs de schistes argileux a la même composition chimique primaire que le gaz naturel contenu dans les réservoirs classiques - constitué de 95% de méthane. La principale différence réside dans les propriétés géologiques et physiques des réservoirs dans lesquels le gaz naturel est stocké plutôt que dans la composition du gaz lui-même. Les gisements de gaz de schiste sont souvent classés comme "non conventionnels" parce qu'ils contiennent du pétrole et du gaz qui ont été produits dans les schistes eux-mêmes et parce qu'ils ne sont pas suffisamment perméables pour permettre au pétrole et au gaz de remonter à la surface naturellement. Par conséquent, le gaz de schiste est produit à partir de schistes à l'aide d'une technologie appelée fracturation hydraulique (fracking) qui crée des fractures artificielles étendues autour des puits de forage. Le forage horizontal est utilisé avec les puits de gaz de schiste. Les longueurs horizontales peuvent atteindre jusqu'à 3000 mètres à l'intérieur du schiste, afin de créer une surface de forage maximale. De grandes quantités d'eau et de produits chimiques sont injectées à haute pression pour créer des fissures dans le schiste argileux et libérer le gaz naturel. Ce dernier est récupéré à partir de puits verticaux.

Le gaz de schiste se trouve dans des "zones pétrolières" de schistes qui sont des formations de

schistes contenant d'importantes accumulations de gaz naturel. Ils ont des propriétés géologiques et géographiques similaires. Une décennie de production provient de la région de Barnett Shale au Texas. L'expérience et les connaissances en matière de mise en valeur des schistes de Barnett ont permis d'améliorer l'efficacité de la production de gaz de schiste dans l'ensemble du pays. Une deuxième zone importante est le schiste argileux de Marcellus dans l'est des États-Unis. Les géologues s'efforcent d'identifier des sites de puits appropriés avec du gaz naturel économiquement récupérable en utilisant une combinaison de techniques d'observation en surface et de cartes du sous-sol générées par ordinateur.

### **A combien sont estimées les réserves de gaz de schiste aux États-Unis ?**

Dans les années 1970, les préoccupations croissantes au sujet de la rareté du gaz naturel ont amené un certain nombre de décideurs et de sociétés d'énergie à orienter leurs efforts vers l'extraction du gaz non classique (Trembath et al., 2012). Trois décennies plus tard, la production de gaz naturel a diminué lentement malgré la hausse des activités de forage. À partir de 2006, l'industrie gazière s'est rendu compte que le gaz de schiste est une ressource importante et économiquement exploitable qui pourrait compléter l'épuisement des puits de gaz classiques. En 2005, l'EIA a fait état d'une augmentation de 6% des réserves prouvées de gaz naturel, soit la plus forte augmentation depuis 1970. En raison des prix élevés du gaz, plus de 32 000 puits d'exploration et de développement ont été forés chaque année entre 2006 et 2008. En 2010, les réserves prouvées de gaz naturel et de pétrole ont atteint les niveaux les plus élevés enregistrés par l'EIA depuis 1977.<sup>1</sup>

Les États-Unis sont devenus le premier producteur de gaz naturel et de pétrole devant la Russie. Cette augmentation a été rendue possible par les progrès technologiques qui ont permis l'exploitation du gaz de schiste, qui n'était auparavant disponible ni techniquement ni économiquement auparavant. En 2000, le gaz de schiste représentait 1,5% de l'approvisionnement en gaz naturel des États-Unis. Le gaz obtenu à partir du schiste argileux représente actuellement 69% de la production gazière américaine et connaît une croissance constante. Selon les prévisions de l'Energy International Information (EIA), la production américaine de gaz naturel s'établira en moyenne à 91,4 milliards de pieds cubes par jour (Gpi3/j) en 2019, en hausse de 8,0 Gpi3/j par rapport à 2018. L'EIA prévoit que la production mensuelle moyenne de gaz naturel augmentera à la fin de

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1. Les réserves prouvées de pétrole brut ont augmenté de 13% (2,9 milliards de barils) et les réserves prouvées de gaz naturel de 12% (33,8 milliards de pieds cubes). Les réserves de pétrole à la fin de 2010 s'élevaient à 25,2 milliards de barils et les réserves de gaz naturel à la fin de 2010 étaient de 317,6 milliards de mètres cubes - la première fois qu'elles ont atteint un niveau supérieur à 300 milliards de mètres cubes.

2019, puis diminuera légèrement au cours du premier trimestre de 2020.

### **Les prix du gaz naturel et leur potentiel impact sur le secteur manufacturier américain**

La Figure 1 montre l'augmentation de la production totale de gaz de schiste aux États-Unis à partir de 2007, ainsi que la variation du prix du gaz naturel aux États-Unis. L'augmentation de l'extraction du gaz de schiste a commencé à la fin des années 2000, s'est accélérée en 2010 et a atteint plus de 10000 milliards de pieds cubes à la fin 2013. En raison de cette croissance soutenue de l'extraction, les prix du gaz naturel aux États-Unis ont chuté considérablement, sans toutefois influencer sur les prix du gaz en Europe en raison de la nature régionalisée des marchés du gaz. Cette évolution a permis aux États-Unis de devenir plus compétitifs vis-à-vis de l'Europe, où le prix du gaz est encore largement indexé sur les prix du pétrole, et est trois à quatre fois plus élevé qu'aux États-Unis. En 2012, le prix du gaz naturel en Europe était en moyenne de 11,40\$ le MBtu, alors qu'il n'était que de 2,75\$ le MBtu aux États-Unis (11,10\$ et 3,45\$ respectivement en août 2013). Le prix du gaz importé en Europe était donc quatre fois plus élevé que les prix américains (contre 2,7 fois plus élevé pour 2009-2013). Ces tendances ont conduit à des prix pour l'industrie européenne qui sont au moins trois fois plus élevés que les prix de l'industrie américaine ; cette différence s'est accentuée au cours des deux dernières années, affaiblissant la position de l'industrie européenne par rapport à celle des États-Unis. La situation est particulièrement problématique pour les industries à forte intensité énergétique confrontées à la concurrence internationale, telles que les produits chimiques, les engrais et l'acier. En raison de la baisse des prix du gaz, les États-Unis sont un endroit attrayant pour l'industrie, en particulier pour la pétrochimie qui utilise d'énormes quantités d'éthylène. L'éthylène est un produit chimique de base utilisé dans des milliers de produits de tous les jours comme les sacs en plastique, les cartons de lait, les matériaux isolants, l'antigel, les jouets et les composants automobiles. Il peut être dérivé du pétrole brut ou du gaz naturel par divers procédés chimiques. Le gaz naturel est une matière première plus efficace pour la production d'éthylène que les autres matières d'hydrocarbures ; par conséquent, l'augmentation de l'offre a entraîné une baisse significative des prix de l'éthane (voir Figure 2).

Enfin, l'augmentation inattendue de l'offre de gaz naturel donne un avantage économique important à l'industrie américaine, ce qui amène certains économistes à parler de la renaissance du secteur manufacturier américain (Wang et al., 2014; Bazilian et al., 2014).<sup>2</sup> L'emploi dans l'industrie

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2. Le secteur industriel est un des plus gros consommateurs de gaz naturel : il comprend les activités manufacturières, agricoles et minières, la construction. Sa consommation s'élève à 8,3 quadrillions de dollars ( $10^{15}$ ) Btu de gaz naturel en 2011, soit environ un tiers de la consommation américaine totale. Toujours en 2011, le gaz naturel

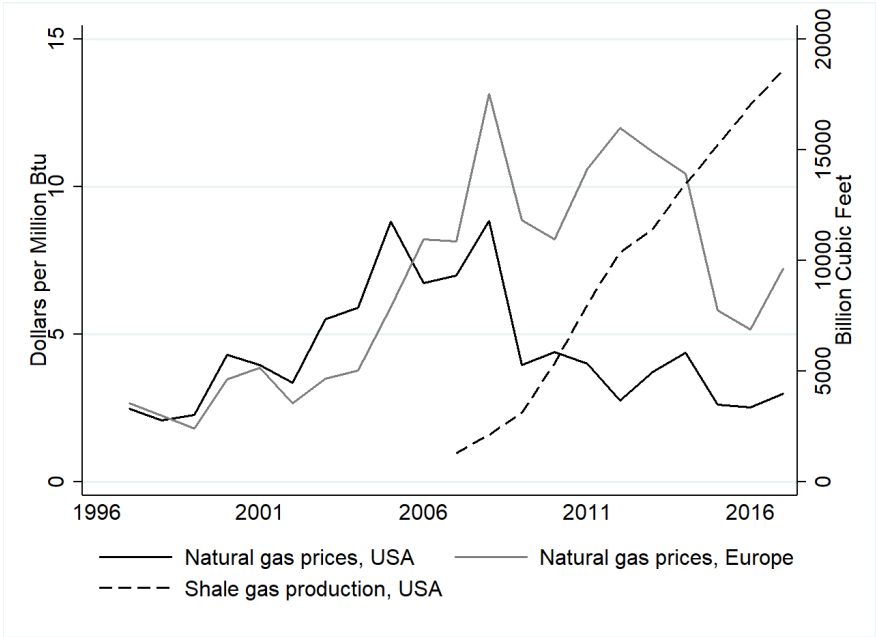


Figure 1: Production du gaz naturel aux Etats-Unis.  
Source: U.S. Energy Information Administration (EIA)

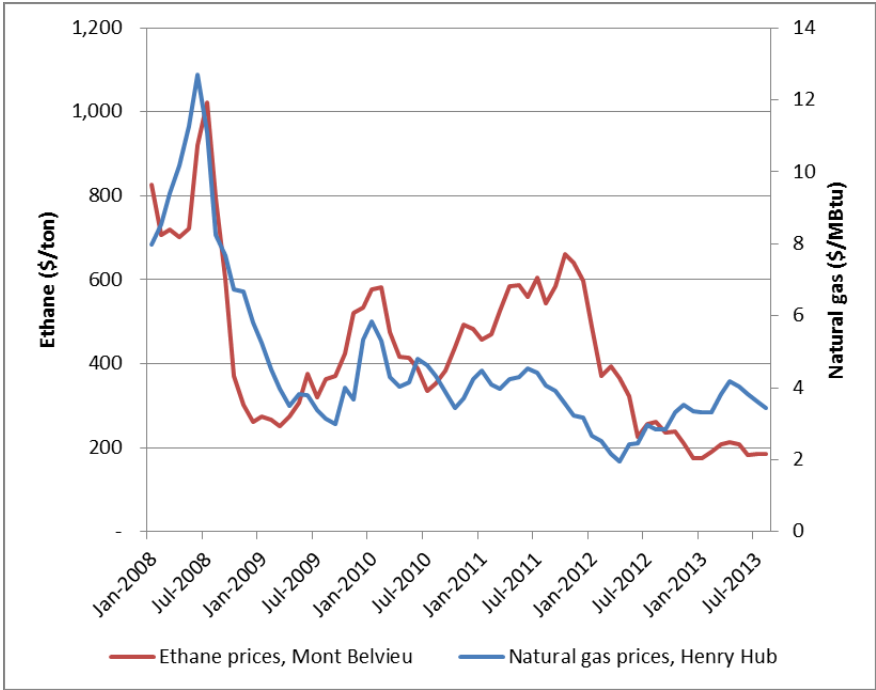


Figure 2: Prix du gaz naturel et de l'éthane aux Etats-Unis.  
Source: Platt's, EIA.



pétrolière et gazière a augmenté de 50 000 emplois en 2012, bien qu'il ne représente qu'une faible part des 2,2 millions de nouveaux emplois créés, si l'on tient compte des effets directs et indirects (Wosepka et al., 2012). Au début de l'année 2013, le Boston Consulting Group (BCG) prévoyait que dans les cinq ans, les États-Unis connaîtraient une renaissance du secteur manufacturier à mesure que les entreprises délocaliseraient leurs activités de fabrication aux États-Unis. Le rapport conclut que les avantages des coûts de production des produits fabriqués à l'étranger ont considérablement diminué au cours de la dernière décennie. En 2003, les coûts de fabrication étaient inférieurs de 18% en Chine par rapport aux États-Unis. En 2011, la différence n'était que de 7%. Natixis, banque de financement et d'investissement française, a confirmé que les avantages concurrentiels dont bénéficient les industriels américains du fait de la baisse des prix du gaz équivalent à une baisse des salaires de 17% par rapport aux entreprises appartenant à la zone euro. Les acteurs de l'industrie manufacturière se sont félicités de l'excédent d'approvisionnement en gaz, qui réduit leurs coûts de production et améliore ainsi leur compétitivité. La baisse du prix de l'énergie peut également créer une croissance significative de l'emploi dans les industries primaires et secondaires. D'autres acteurs considèrent le développement du gaz naturel comme une opportunité d'utiliser moins de charbon dans la production d'électricité et de réduire la dépendance au pétrole par la liquéfaction du gaz dans le secteur des transports. Les producteurs de gaz, quant à eux, ont vu une excellente occasion de tirer profit de l'exportation de gaz naturel sous forme de gaz naturel liquéfié (GNL).

La découverte des ressources non conventionnelles peut stimuler les économies développées qui dépendent fortement des énergies fossiles issues des régions moins développées. Cependant, qu'en est-il de l'impact des ressources naturelles sur l'économie des pays qui ne sont pas développés? La découverte récente d'importantes réserves de pétrole et de gaz en Afrique de l'Est offre des possibilités de développement économique dans la région et alimente le débat sur l'abondance des ressources naturelles et le lien avec la croissance. Le Mozambique a découvert quelques plus grands gisements de gaz naturel au monde, tandis que la Tanzanie, l'Ouganda et le Kenya ont également découvert du gaz et du pétrole (Zhang et al., 2019). Les travaux d'exploration sont toujours en cours, de sorte que d'autres découvertes pourraient être faites. Cela donne à cette région et à d'autres une chance de développer leurs économies. Ces gouvernements s'attendent à recevoir d'importantes recettes du secteur pétrolier et gazier qui pourront servir à mettre en œuvre des politiques visant à accroître les possibilités de croissance économique, à promouvoir le développement économique durable, à réduire la pauvreté et à améliorer le niveau de vie. Cependant, cette op-

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représentait plus de 40% de l'énergie utilisée dans le secteur industriel.

portunité n'est pas sans risques et défis, souvent appelés la malédiction des ressources. La section suivante nous permet de poser les bases d'une discussion sur la malédiction des ressources.

### **La malédiction des ressources naturelles : l'abondance en ressources naturelles nuit-elle au développement économique ?**

La théorie des avantages comparatifs montre qu'une dotation en ressources naturelles confère à une nation un avantage par rapport aux autres qui se traduit par une richesse nationale accrue, toutes choses étant égales par ailleurs. Cette hypothèse d'inspiration ricardienne n'est guère étayée dans la pratique. L'écart de revenu entre les pays riches et les pays pauvres en ressources s'est creusé entre 1960 et 1990 en faveur des pays pauvres en ressources. En effet, une trop grande dépendance à l'égard des ressources naturelles a souvent été liée à de mauvais résultats macroéconomiques et à des inégalités croissantes. Le sujet a été un domaine de recherche important. Cependant, il existe peu de consensus sur l'effet de la richesse des ressources naturelles sur la croissance économique et les mécanismes sous-jacents de cet effet. Un certain nombre de canaux de transmission ont été identifiés dans la littérature afin de d'expliquer le phénomène de la malédiction des ressources popularisée par Sachs and Warner (1995). Ces canaux peuvent être divisés en deux catégories différentes, mais qui se chevauchent: les explications économiques et politiques.

Les premières explications économiques classiques de la malédiction des ressources sont fondées sur la théorie du syndrome hollandais. Le terme "syndrome hollandais" provient de l'expérience néerlandaise d'un secteur manufacturier en déclin après la découverte d'importantes réserves de gaz naturel dans les années 1950. Les modèles du syndrome hollandais mis au point par Corden and Neary (1982) et Van Wijnbergen (1984) montrent comment une nouvelle découverte de ressources naturelles dans un pays peut nuire au revenu national par des effets négatifs sur le mécanisme d'apprentissage par la pratique et d'autres mécanismes du secteur manufacturier. Les effets négatifs peuvent se manifester parce que l'exploitation des ressources naturelles attire la main-d'œuvre du secteur manufacturier vers le secteur extractif en raison d'une rémunération plus attrayante des employés. En conséquence, le secteur manufacturier connaît une pénurie de main-d'œuvre et des coûts d'intrants plus élevés. D'autre part, l'augmentation des recettes minières conduit le gouvernement à augmenter ses dépenses qui seront en partie consacrées à des biens non échangeables tels que la construction et les services. Les prix des biens et services non échangeables augmentent, ce qui entraîne une appréciation du taux de change réel. Par conséquent, la croissance économique diminue à mesure que la production manufacturière et les exportations de produits autres que les matières

premières diminuent en raison des coûts de main-d'œuvre plus élevés dans le secteur manufacturier et du taux de change réel plus élevé, qui rend les exportations de produits autres que les hydrocarbures plus chères et moins compétitives. Sur la base de ces modèles, Krugman (1987) et Matsuyama (1992) ont développé une série de modèles théoriques du "syndrome hollandais" pour lesquels ils supposent tous que la croissance de la productivité dans le secteur manufacturier est déterminée par le learning by doing. Ils discutent de la façon dont le syndrome hollandais peut apparaître par différents canaux tels que l'augmentation des rendements d'échelle du commerce, la productivité agricole et la volatilité des taux de change. Des travaux universitaires plus récents améliorent les modèles existants et en déduisent différentes interprétations concernant le syndrome hollandais (Torvik, 2001; Sachs and Warner, 2001; Matsen and Torvik, 2005; Van der Ploeg and Venables, 2013; Cherif, 2013). L'autre canal économique comprend la volatilité des prix des ressources. Dans les pays riches en ressources naturelles, la principale source de revenus est généralement le secteur extractif. Toutefois, les prix des énergies fossiles peuvent fluctuer considérablement, ce qui nuit à la capacité des gouvernements à bien gérer leur rente énergétique. L'instabilité macroéconomique qui résulte de la volatilité des prix des ressources naturelles peut également décourager l'investissement (Van der Ploeg and Poelhekke, 2009). Van der Ploeg and Poelhekke (2009) a trouvé que les effets positifs des ressources naturelles sur la croissance sont éclipsés par leurs effets négatifs indirects liés à la volatilité des ressources naturelles. Finalement, les ressources naturelles exacerbent la volatilité macroéconomique (Bleaney and Halland, 2009; Malik and Temple, 2009; Frankel, 2010). De nombreuses études empiriques confirment la relation négative qui existe entre volatilité et croissance (Aizenman and Pinto, 2004; Loayza and Hnatkowska, 2004; Ramey and Ramey, 1994).

Quant aux canaux de transmission politiques de la malédiction des ressources, de nombreux économistes, tels que Sachs and Warner (2001), Hodler (2006) et Iimi (2007) soutiennent que dans certains pays, la manne des revenus des ressources naturelles accroît le pouvoir des élites, qui ont la capacité d'accroître les inégalités de revenus. Les élites ou les groupes puissants prennent généralement une grande partie de ces revenus et les distribuent au profit de leur entourage immédiat, plutôt que de les investir dans la modernisation des infrastructures et le développement économique durable. Les recettes exceptionnelles tirées de l'exploitation des ressources naturelles sont également considérées comme l'une des principales causes de conflit entre les parties prenantes nationales telles que les politiciens, les tribus locales et les citoyens (Sala-i Martin and Subramanian, 2013; Davis and Tilton, 2005). Collier and Hoeffler (2004) montre que le risque de guerre civile dans un pays africain varie de moins de 1% dans les pays sans ressources naturelles à près de 25% pour les pays qui en disposent (Ross et al., 2011). Les autres principaux canaux de transmission politiques

suggèrent que la faiblesse des institutions est la principale raison de la malédiction des ressources (Arezki and van der Ploeg, 2010; Robinson et al., 2006). Les ressources naturelles peuvent avoir un impact négatif sur les institutions: les pays riches en ressources ont tendance à avoir un gouvernement centralisé qui entre en collusion avec l'industrie minière. De plus, les revenus des ressources peuvent servir à calmer la protestation des citoyens et à réprimer les opposants politiques (Karl, 1997). L'abondance des ressources fait monter en flèche le niveau de corruption dans les pays où les institutions démocratiques sont faibles, mais les résultats ne sont pas les mêmes dans les pays où les institutions démocratiques sont fortes (Bhattacharyya and Hodler, 2010). Tornell and Lane (1999) considèrent que la faiblesse des institutions est responsable de la faible croissance économique enregistrée au Nigeria, au Mexique et au Venezuela après la découverte du pétrole dans ces pays. Sala-i Martin and Subramanian (2013) constatent que la corruption qui est apparue après la découverte du pétrole est responsable de la faible croissance du Nigeria. Enfin, Mehlum et al. (2006) affirment également que de bonnes institutions sont essentielles pour résoudre la malédiction des ressources.

Les résultats empiriques sur le paradoxe de la malédiction des ressources naturelles sont mitigés. Rodriguez and Sachs (1999) et Gylfason (2001) entre autres confirment les résultats de Sachs et Warner concernant l'effet négatif du niveau d'abondance des ressources sur la croissance économique. Cependant, Brunnschweiler and Bulte (2008) affirment que la malédiction des ressources n'est plus valide quand on utilise la bonne mesure de l'abondance des ressources (plutôt que la dépendance) dans les régressions de croissance. Il existe également un nombre croissant d'articles fournissant des preuves contre le paradoxe de la malédiction des ressources. Alexeev and Conrad (2009) et Cotet and Tsui (2013) ne trouvent aucune preuve soutenant la malédiction des ressources naturelles. Bien au contraire, en étudiant les pays disposant de grandes ressources pétrolières, ils constatent que ces pays affichent une croissance plus élevée de leurs revenus. De plus, Smith (2015) évalue l'impact des découvertes majeures de pétrole depuis 1950 sur le PIB par habitant. À l'aide de différentes méthodes quasi expérimentales, comme la méthode de contrôle synthétique, il constate que les découvertes de pétrole ont un impact positif sur la croissance à long terme.

Dans de nombreux pays riches en ressources naturelles, les gouvernements sont confrontés à deux défis importants et connexes en ce qui concerne les rentes des ressources : quelle part de la rente des ressources devrait être dépensée ? économisée ? comment dépenser les revenus ? Les ressources sont épuisables, la rente peut être affectée par le régime fiscal, varie avec les prix mondiaux de l'énergie et le taux d'extraction des ressources. Les pays en voie de développement riches en ressources naturelles doivent définir leurs objectifs et prendre des décisions en vue d'une croissance soutenue et de la réduction de la pauvreté.

Pour trouver des solutions à ces défis, il faut comprendre le type de ressources disponibles, ainsi que l'aspect technique et la situation économique globale du pays. En effet, les types de réserves (gaz ou pétrole), la qualité du pétrole brut ou du gaz naturel et les défis techniques de la production (niveau de profondeur, onshore ou offshore) affectent les coûts associés à l'extraction de la ressource, et donc les taux de rendement attendus pour la compagnie pétrolière et les recettes fiscales du gouvernement. Le niveau des taux d'imposition et les types d'instruments fiscaux (redevances, limites de recouvrement des coûts, impôts sur les sociétés, déductions pour amortissement, etc.) influent sur l'exploitation finale de la ressource naturelle et le profil temporel de l'extraction (Petty et al., 2015). Celles-ci peuvent avoir un impact non seulement sur le profil de temps d'extraction de la ressource, mais aussi sur la répartition des rentes de la ressource entre les parties prenantes.

Enfin, grâce à Shell et BP, ainsi qu'aux autres compagnies pétrolières, des investissements croissants dans l'exploration et le forage de nouveaux gisements, conventionnels et non conventionnels, créent des possibilités de développement économique futur. Simultanément, la combinaison de réserves économiquement récupérables non conventionnelles et conventionnelles représente plus du double de la quantité de carbone qui pourrait être rejetée dans l'atmosphère. Toutefois, pour éviter un changement irréversible du climat et ses impacts négatifs, il faut limiter à 500 milliards de tonnes (gigatonnes ou Gt) les émissions totales de carbone dans l'atmosphère. Nous avons déjà émis 370 Gt depuis le début de la révolution industrielle, ce qui laisse une limite de 130 Gt qui pourrait être ajoutée. Par conséquent, le développement récent des combustibles fossiles non conventionnels et leur empreinte carbone potentielle est incompatible avec une limite inférieure à 500 Gt. Ces découvertes croissantes constituent une menace réelle pour la lutte contre le changement climatique. Par ailleurs, étant donné que le lien entre croissance et émissions est encore très débattu (EKC), peut-on enfin se demander si la question des émissions est totalement déconnectée de celle des pays riche en ressources naturelles? Le fait d'avoir une ressource disponible, qui est souvent moins chère que pour les pays importateurs, n'a-t-il pas d'effets secondaires sur les efforts d'efficacité énergétique, les décisions nationales concernant le mix énergétique et la lutte contre le changement climatique ? La section suivante nous permet de poser les bases d'une discussion sur la théorie de la malédiction du carbone.

### **Ressources naturelles et changement climatique**

La consommation d'énergie et les émissions de gaz à effet de serre deviennent des préoccupations majeures à la suite d'observations de plus en plus alarmantes sur le changement climatique. En

septembre 2013, le Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC) s'est réuni à Stockholm pour présenter ses résultats, qui renforcent ses conclusions antérieures. Le réchauffement climatique s'accélère. La température à la surface de la terre et de l'océan a augmenté de  $0,85^{\circ}\text{C}$  en moyenne depuis 1880. Le GIEC prévoit une augmentation de la température de  $0,3^{\circ}\text{C}$  à  $4,8^{\circ}\text{C}$  pour ce siècle selon les différents scénarios. Une telle augmentation aurait un impact non négligeable sur le nombre d'événements climatiques extrêmes. Par exemple, 2012 a été l'une des dix années les plus chaudes jamais enregistrées. Cela a provoqué plusieurs événements climatiques inhabituels, tels que les niveaux les plus bas enregistrés de glace de mer de l'Arctique (97% de la calotte glaciaire du Groenland présentait certaines formes de fonte Swindles et al. (2013), l'ouragan Sandy aux États-Unis, les fortes précipitations en Europe du Nord et en Australie orientale.

Tout d'abord, les catastrophes naturelles ont causé un certain nombre de décès, dont environ 8 800 en 2012. Deuxièmement, outre les pertes en vies humaines, les dommages liés aux catastrophes naturelles représentent un coût très élevé. Les événements survenus en 2012 représentent une perte économique de 200 milliards de dollars (Benfield, 2014). L'ouragan Sandy a été l'événement le plus coûteux de l'année et explique la sécheresse aux États-Unis pour la moitié des pertes économiques. Il ne s'agit pas d'un coût exceptionnel: 2012 a été la cinquième année la plus coûteuse en termes de pertes économiques depuis 2002. Troisièmement, toutes les conséquences de ces changements climatiques ne sont pas observables aujourd'hui. Le niveau de la mer continuera d'augmenter à la suite de l'élévation de la température, ce qui augmenterait la fréquence et aggraverait l'intensité de catastrophes telles que les tempêtes et les inondations. Le rapport Sustainability (2011) souligne le fait que les dégradations environnementales ou la destruction des habitats pourraient menacer le développement et accroître la pauvreté dans les pays émergents. Dans ce rapport, l'impact des événements climatiques sur l'indice de développement humain (IDH) est estimé en tenant compte de plusieurs scénarios. Le scénario du " défi environnemental " illustre les effets néfastes du réchauffement climatique sur la production agricole, sur l'accès à l'eau potable et à un assainissement amélioré, et sur la pollution. Le scénario d'une " catastrophe environnementale " se caractérise par une déforestation et une dégradation des terres considérables, un déclin dramatique de la biodiversité et des phénomènes météorologiques extrêmes accélérés. Les simulations suggèrent que l'IDH mondial serait inférieur de 8% d'ici 2050 dans le scénario " défi environnemental ", et même de 12% pour l'Asie du Sud. Le scénario " catastrophe environnementale " prévoit un IDH mondial inférieur de 15% au niveau de référence. Plusieurs mécanismes jouent un rôle. Le même rapport montre que les événements climatiques, comme les sécheresses en Afrique et l'élévation du niveau de la mer dans les pays de basse altitude à l'instar du Bangladesh, pourraient conduire à

une augmentation des prix alimentaires mondiaux de 30 à 50%, touchant en premier lieu les pays les plus pauvres.

Compte tenu des conséquences dramatiques, il existe aujourd'hui un large consensus sur la nécessité pour la communauté internationale de s'attaquer au problème du changement climatique. La lutte contre le changement climatique a commencé avec les discussions de la Conférence des Nations unies sur l'environnement à Stockholm en 1972. Vingt ans plus tard, la Convention-cadre des Nations unies sur les changements climatiques (CCNUCC) a été mise en place pour négocier la réduction des émissions de gaz à effet de serre. Grâce à la CCNUCC, le premier accord international, le Protocole de Kyoto, a été adopté en 1997 au Japon. Il énonce des engagements juridiquement contraignants en matière d'émissions et des mécanismes de marché qui permettent aux pays industrialisés de mobiliser les solutions d'atténuation mondiales les plus rentables. Conformément au Protocole de Kyoto, la plupart des pays développés se sont engagés à réduire globalement leurs émissions de gaz à effet de serre de 5% par rapport au niveau de 1990. Cette coopération internationale se poursuit avec le récent Accord de Paris sur le climat qui définit un nouvel accord climatique contraignant pour tous les pays. Elle limite l'augmentation de la température moyenne mondiale à 1,5°C au-dessus des niveaux préindustriels. Toutefois, ces objectifs ne peuvent être atteints que si les pays acceptent de réduire les émissions provenant de la combustion de combustibles fossiles, car les émissions provenant de ces sources entraînent une augmentation significative des gaz à effet de serre.<sup>3</sup>

Compte tenu de l'accroissement de la population mondiale, de la concurrence et des problèmes environnementaux auxquels tous les pays sont confrontés, il est important pour eux de passer des combustibles fossiles à des sources d'énergie plus propres afin de satisfaire leur demande croissante en énergie. L'un des défis futurs de notre société est de maintenir la croissance économique tout en préservant ou en développant le capital naturel de la Terre. Une partie de la littérature de recherche sur l'économie et l'énergie se concentre sur ce point, c'est-à-dire sur le découplage entre la dégradation de l'environnement et la croissance économique. Il existe deux types de découplage: relatif et absolu. Le découplage relatif implique que les émissions augmentent plus lentement que la croissance économique. Le découplage absolu implique que les émissions diminuent alors que l'économie croît (Giorgetti, 2007). Certains chercheurs soutiennent que le découplage est un processus "naturel" qui se produit automatiquement lorsque les économies croissent. D'autres

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3. Les combustibles fossiles représentaient 84% de la consommation mondiale d'énergie en 2012, et environ 2/3 des émissions mondiales de gaz à effet de serre sont dues à l'approvisionnement en énergie et à l'utilisation des combustibles fossiles.

affirment que ce sont les actions politiques qui sont la principale raison de la réduction des émissions et de la protection de l'environnement (Persson et al., 2006).

### **La courbe environnementale de Kuznets**

Pour parvenir à un équilibre sain entre la croissance économique et la protection de l'environnement, il est nécessaire de modifier sensiblement nos modes de consommation énergétique à l'échelle mondiale. Au cours des trois dernières décennies, le lien entre la croissance économique et la pollution de l'environnement a suscité un grand intérêt. Grossman and Krueger (1991) introduit l'idée de la courbe de Kuznets environnementale (EKC) dans un document pour une conférence sur l'Accord de libre-échange nord-américain (ALENA).<sup>4</sup> Grossman and Krueger (1991) ont étudié l'évolution de la production de dioxyde de soufre, de fumée et de particules en suspension dans les zones industrielles de 12 pays. Ils constatent que pour deux polluants (dioxyde de soufre et fumée), les concentrations augmentent avec le PIB par habitant à de faibles niveaux de revenu national, mais diminuent à mesure que les niveaux de revenu augmentent. Leurs conclusions sont particulièrement intéressantes pour les économistes et les analystes des politiques en raison de leur importance dans la mise en œuvre des politiques économiques. En effet, si la relation supposée semble valable pour tous les pays, au lieu de constituer une menace pour l'environnement, la croissance économique est le moyen par lequel le développement économique durable peut être réalisé, comme le montre la figure 3 ci-dessous.

La question de savoir si la dégradation de l'environnement augmente ou diminue avec le développement économique a été étudiée pour un large éventail de polluants, tels que les émissions de plomb des voitures, la déforestation, les émissions de gaz à effet de serre, les déchets toxiques et la pollution atmosphérique intérieure.<sup>5</sup> Différentes méthodes économétriques ont été utilisées afin d'analyser la relation entre revenu et pollution. Elles utilisent les polynômes d'ordre supérieur, les effets fixes et aléatoires, les splines, les techniques semi-paramétriques et non-paramétriques, ainsi que différents modèles et termes d'interaction. En conclusion, la relation entre niveau de développement et pollution diffèrent d'un pays à l'autre. Pour certains pays, les seuils de retournement se situent à des niveaux de revenu très élevés, voire pas de seuil du tout. En définitif, les preuves empiriques sont plutôt mitigées.

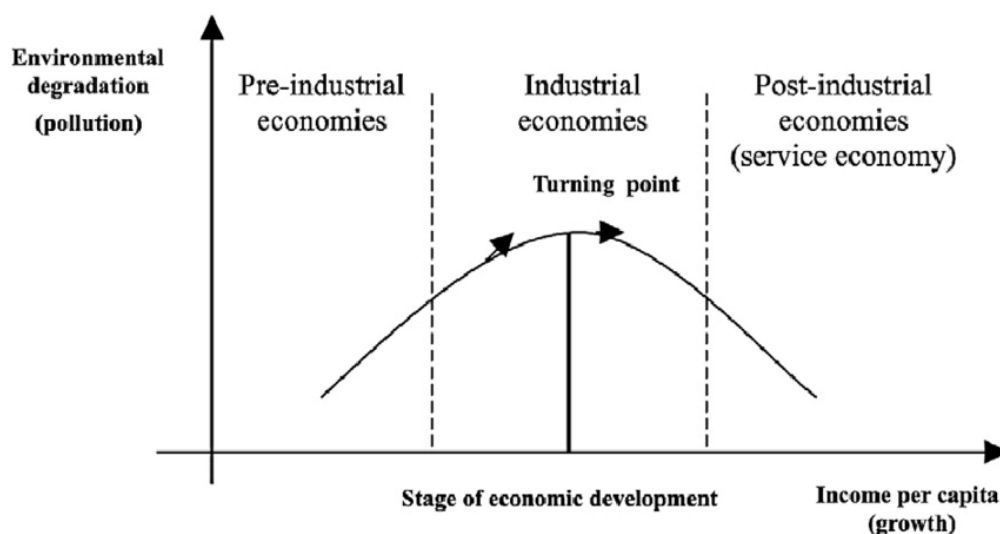
Plusieurs études théoriques tentent d'expliquer la relation entre la croissance du revenu et la pol-

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4. Une clause de l'ALENA suppose qu'il y aura un transfert transfrontalier au Mexique de la production qui pose un problème environnemental aux États-Unis et au Canada.

5. Ces indicateurs se sont révélés être l'approximation de la qualité de l'environnement la plus couramment utilisée.





Source: Panayotou (1993)

Figure 3: The Environmental Kuznets Curve.  
Source: Panayotou (1993).

lution sur la base de deux approches différentes: la première soutient que la croissance économique nuit à l'environnement (Meadows et al., 1972), tandis que la seconde soutient que le processus technologique et la croissance économique améliorent la qualité environnementale (Panayotou et al., 1993; Brock and Taylor, 2005). Selon Brock and Taylor (2005), plus la croissance d'une économie est forte, plus toutes les activités se développent et plus le niveau de pollution est élevé. Mais à mesure que l'activité économique passe d'industries énergivores à des industries plus propres, les émissions diminuent en raison de l'effet de composition et, à mesure que les investissements dans les technologies propres deviennent plus efficaces, le développement durable est réalisé. Arrow et al. (1995) affirment également que les conditions environnementales ont tendance à se détériorer aux premiers stades du développement économique, alors que lorsque les sociétés atteignent des stades avancés, elles ont tendance à accorder une plus grande attention à la qualité de l'environnement par le biais des mécanismes du marché et des politiques de réglementation. Toutefois, ces auteurs ont mis en garde contre l'idée que l'EKC pourrait suggérer que les questions environnementales nationales et internationales seraient traitées dans le cadre de processus autonomes propres à chaque pays. Par ailleurs, Lopez and Mitra (2000) montre que l'EKC peut s'expliquer en termes de préférences des agents économiques. Il soutient que si les préférences sont homothétiques, des revenus plus élevés se traduisent par une consommation plus élevée, ce qui se traduit à son tour par une production plus élevée et, en fin de compte, un niveau de pollution plus élevé. Mais si les préférences ne sont plus homothétiques et que les revenus augmentent, les individus peuvent vouloir consommer moins

et donc polluer moins, en fonction de leur aversion relative au risque entre consommation et qualité de l'environnement. Une autre approche théorique soutenant l'EKC suppose que l'environnement est un bien de luxe, ce qui signifie que si les revenus augmentent de 1%, la demande de qualité environnementale augmente de plus de 1%. En utilisant un échantillon de pays de l'Union européenne (UE), McConnell (1997) montre que la qualité de l'environnement est un bien normal avec une élasticité de la demande au revenu légèrement inférieure à un.

Les études qui ont examiné la relation entre la croissance économique et la qualité de l'environnement ont utilisé toute une série d'indicateurs environnementaux, de pays, de régions, de secteurs et de techniques économétriques avancées. Cependant, les résultats sont loin d'apporter une réponse définitive. L'écart dans les résultats peut être attribué à plusieurs facteurs, tels que le type de données utilisées et la méthodologie appliquée. D'autres facteurs peuvent également modifier la nature de cette relation, comme le degré de libéralisation économique, la réglementation environnementale, l'aménagement historique des terres et l'incidence des conditions météorologiques. Par conséquent, le fait de ne pas tenir compte de ces variables dans l'analyse des relations peut fausser la trajectoire de la pollution par rapport au revenu. Compte tenu de ces limites, certains chercheurs ont fait preuve de prudence dans l'interprétation des résultats et s'attellent à réclamer des mesures d'atténuation au moyen de réglementations environnementales (Dasgupta et al., 2002).

### **Changement climatique: pays riches en ressources versus les pays pauvres en ressources**

Les pays riches en ressources naturelles sont une catégorie négligée dans les débats politiques actuels sur l'atténuation du changement climatique. Jusqu'à présent, ces débats ont surtout porté sur le clivage entre économies établies et économies émergentes. Ce qui a été négligé, c'est le clivage transversal entre les pays riches en ressources naturelles et les pays pauvres en ressources naturelles. Dans les économies pauvres en ressources, la logique de rareté des ressources limite l'intensité carbone. Dans les économies riches en ressources, en revanche, la logique de l'abondance des ressources produit l'effet contraire. Par conséquent, les pays riches en ressources nécessitent une attention particulière. Il est nécessaire de mieux faire connaître les économies riches en combustibles et les obstacles qu'elles doivent surmonter pour maintenir leur intensité carbone dans des limites acceptables. L'étude du rôle des pays riches en ressources naturelles aidera à orienter le débat sur le climat dans une direction plus productive et à obtenir une image complète des défis fondamentaux qui rendent si difficile la réduction globale des émissions mondiales de CO<sub>2</sub>.

## Evidence de la malédiction du carbone

La théorie de la malédiction du carbone établit un lien entre la dotation en combustibles fossiles d'un pays et l'intensité en carbone de sa production économique. Son hypothèse principale est que la dotation en combustibles fossiles d'un pays détermine son intensité en carbone et qu'il est difficile pour les pays riches en combustibles fossiles d'empêcher que cela ne se produise.

Pour illustrer la relation globale entre l'abondance des ressources naturelles et l'intensité énergétique, la figure 4 classe les pays en fonction de l'intensité en CO<sub>2</sub> (par unité de PIB). Les pays indiqués en rouge sont riches en ressources.<sup>6</sup>

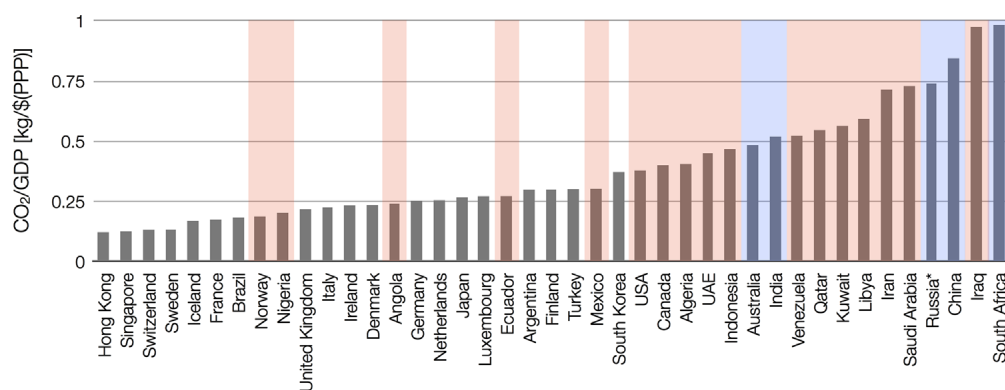


Figure 4: Intensités en carbone en 2008. Les pays riches en pétrole sont indiqués en rouge, les pays riches en charbon en bleu.

Source: <http://data.un.org>.

Parmi les vingt pays où l'intensité en CO<sub>2</sub> est la plus élevée, dix-huit sont des pays riches en ressources (en rouge et en bleu). Une relation positive significative peut être facilement observée dans cette figure. Cependant, la corrélation elle-même n'est pas une relation de cause à effet. Des situations typiques se présentent, telles que les pays riches en ressources naturelles avec de faibles émissions de CO<sub>2</sub> (Norvège, Nigeria, Angola, Equateur). Les effets de l'abondance des ressources naturelles sur l'intensité des émissions de CO<sub>2</sub> ne sont toujours pas évidents.

La figure 5 de Friedrichs and Inderwildi (2013) montre le processus de décarbonisation des pays entre 1996 et 2008. Ils sont divisés en trois catégories: réduction des émissions (vert), augmentation des émissions (jaune) et intensification des émissions (rouge). Dans le panel supérieur gauche, tous les pays de l'échantillon sont représentés, tandis que les trois autres panels correspondent à des sous-groupes spécifiques: les vingt pays les plus industrialisés (G20), les quinze économies les plus

6. Les pays riches en pétrole marqués en rouge, les pays riches en charbon en bleu.

avancées en haute technologie telles que définies par le Global Competitiveness Report (Schwab, 2012) et les douze pays de l'OPEP. Nous constatons que sept pays réussissent à se décarboniser plus rapidement que leur économie ne croît, ce qui se traduit par une réduction absolue des émissions de CO<sub>2</sub> (zone verte). A l'exception du Royaume-Uni, ils sont tous très développés, techniquement avancés et pauvres en carburant. A l'inverse, les pays qui ont connu une augmentation massive des émissions de carbone (zone rouge) due à l'accélération de la croissance économique et à l'augmentation de l'intensité carbone partagent les caractéristiques suivantes: ils sont tous de grands producteurs de pétrole ou de charbon et, sauf la Norvège, membres de l'Organisation des pays exportateurs de pétrole (OPEP). Entre les deux, les zones jaunes représentent les pays qui ont réussi à réduire leur intensité carbone, mais qui ont quand même connu une augmentation absolue de leurs émissions de carbone en raison de taux de croissance économique plus élevés. Le groupe se compose des plus grandes économies du monde telles que la Chine, les États-Unis et l'Inde.

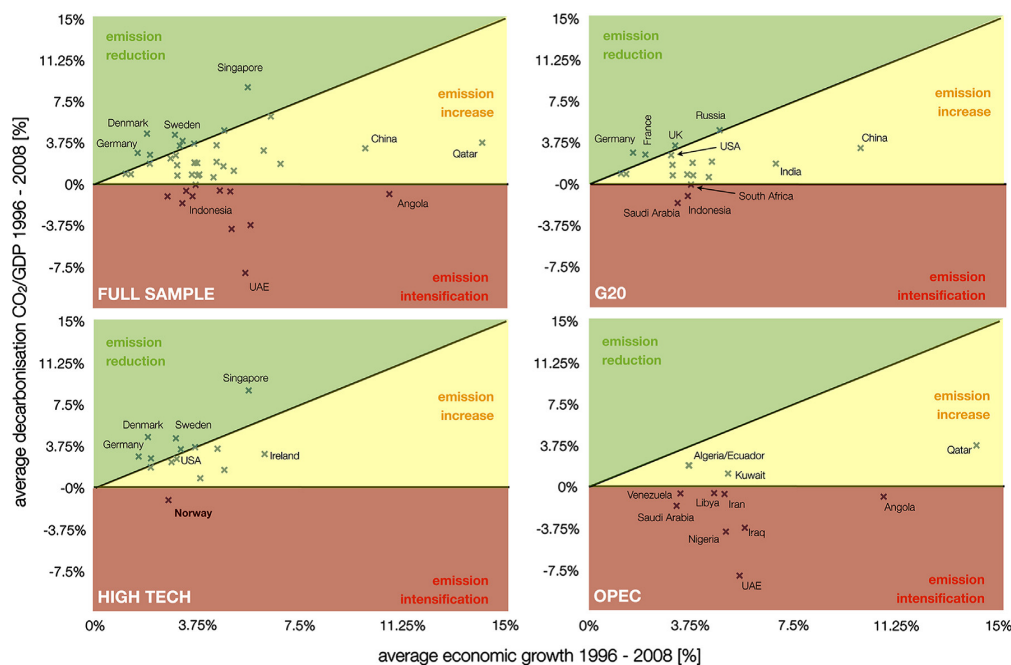


Figure 5: Trajectoires en intensité carbone traduites par l'augmentation ou la diminution annuelle moyenne de l'intensité carbone par rapport aux taux de croissance économiques moyens entre 1996 et 2008.

Source: <http://data.un.org>.

La section suivante présente plus en détail les contributions, les objectifs, la méthodologie et les résultats de chaque chapitre.

## Contributions

### Chapitre 1: "The actual impact of shale gas revolution on the U.S. manufacturing sector".

Ce chapitre fournit une évaluation claire de l'impact de la production de gaz de schiste sur le secteur manufacturier américain. Plus précisément, il évalue l'impact sur cinq variables macroéconomiques que sont la production industrielle, l'investissement, l'emploi, les importations et les exportations, de la différence de prix du gaz naturel entre les États-Unis et l'Europe, en utilisant des données annuelles pour un groupe de 80 industries sur la période 1997-2013. L'utilisation des prix du gaz pour estimer l'effet du gaz de schiste est justifiée par le choc d'offre positif survenu en 2006 sur le marché américain du gaz en raison de l'exploitation massive du gaz de schiste (Wakamatsu and Aruga, 2013; Aruga, 2016; Caporin and Fontini, 2017). Par conséquent, les prix du gaz aux États-Unis ont baissé depuis 2006. La construction de la variable mesurant les prix du gaz naturel aux États-Unis par rapport aux prix européens permet de capturer l'avantage comparatif conféré au secteur manufacturier américain.

La première contribution de ce chapitre est de construire une variable "intensité énergétique" à partir de l'enquête MECS (Manufacturing Energy Consumption Survey) réalisée en 2006. En effet, cette variable donne une indication précise des industries les plus susceptibles de profiter de la baisse des prix du gaz, puisqu'elle donne des informations sur les niveaux de consommation de gaz et d'énergie proches de la date du choc d'offre positif sur le marché américain du gaz naturel. Ensuite, en multipliant ce ratio des prix par l'intensité énergétique de chaque industrie, on peut construire une nouvelle variable, plus pertinente. Elle distingue l'avantage des différents secteurs en fonction de leur intensité énergétique. En effet, cette nouvelle variable présente un double avantage. Le premier consiste à obtenir une mesure des avantages comparatifs sectoriels. Le deuxième avantage est d'ordre économétrique, car la nouvelle approximation crée plus de variabilité dans les données, ce qui améliore l'efficacité des estimateurs utilisés. Deuxièmement, comme le prix du gaz naturel a fortement chuté depuis 2006, nous vérifions l'hypothèse d'une rupture structurelle dans la relation entre nos cinq variables et les prix du gaz naturel, et nous trouvons des ruptures structurelles uniquement pour les importations et les exportations. Enfin, nous estimons des modèles de panel dynamiques qui permettent de calculer les élasticités à court et à long terme.

Les résultats indiquent que la baisse des prix du gaz naturel aux États-Unis par rapport au prix du

gaz naturel en Europe a entraîné une augmentation de l'activité industrielle et des investissements de près de 3% pour l'ensemble du secteur manufacturier. En tenant compte des ruptures structurelles, on constate que les exportations augmentent de près de 1%, alors que les importations diminuent de près de 1%. Quant à l'impact sectoriel, les résultats se caractérisent par une forte disparité. En effet, l'activité industrielle du secteur le plus intensif réagit à la baisse des prix du gaz par une hausse d'au moins 30%. Enfin, même si certaines industries sont en expansion, cela ne semble pas avoir un grand effet sur l'ensemble du secteur manufacturier jusqu'à maintenant. Ces résultats doivent être interprétés avec prudence étant donné que les entreprises n'adaptent leurs processus de production que progressivement.

## **Chapitre 2: "Carbon Curse in Developed Countries" co-écrit avec Mireille Chiroleu-Assouline et Mouez Fodha.**

Dans ce chapitre, nous cherchons à déterminer empiriquement si un pays riche en ressources naturelles est plus polluant qu'un autre pays et si l'abondance des ressources naturelles affecte tous les secteurs de l'économie. Notre objectif est de contribuer au débat sur l'atténuation du changement climatique en mesurant les conséquences de l'abondance des ressources naturelles sur les émissions à différents niveaux: national et sectoriel. Les relations entre les ressources et la croissance économique ont déjà été largement discutées dans la littérature. Des études concluent à l'existence de liens entre les ressources naturelles et la croissance économique (malédiction des ressources), alors que d'autres études se concentrent sur les interactions entre les niveaux de pollution et la croissance économique (la courbe de Kuznets environnementale EKC). Notre travail se situe à l'intersection de ces deux domaines de la littérature, car nous étudions plus généralement la relation entre les ressources naturelles et les émissions de CO<sub>2</sub> pour tester l'hypothèse de la malédiction du carbone. A notre connaissance, cette étude est la première à aller au-delà d'une simple analyse statistique descriptive en proposant des tests économétriques de l'hypothèse de la malédiction du carbone.

Les principales intuitions des mécanismes en jeu pour une malédiction du carbone sont les suivantes. Le premier est un effet de composition induit par la prédominance des secteurs des combustibles fossiles qui émettent massivement du CO<sub>2</sub>. Deuxièmement, il y a les effets d'éviction dans le secteur de la production d'énergie, qui constituent un obstacle au développement des sources d'énergie renouvelables. Troisièmement, il y a les retombées dans d'autres secteurs de l'économie, qui sont

combinées à des politiques moins strictes. Par conséquent, pour analyser en profondeur les interactions entre les ressources naturelles et la pollution, nous considérons les données macroéconomiques et sectorielles d'un groupe de pays développés. Notre base de données comprend 29 pays, et s'étend sur 15 ans (1995–2009) ; elle révèle une grande hétérogénéité entre les pays. Nos données sectorielles portent sur sept secteurs.

Les résultats montrent que l'interaction entre l'intensité  $\text{CO}_2$  du PIB et l'abondance des ressources n'est pas monotone. Plus précisément, nous montrons qu'il existe une relation en forme de U entre l'intensité en  $\text{CO}_2$  et la dotation en ressources au niveau national: plus un pays est riche en ressources naturelles, plus il émet de  $\text{CO}_2$  par unité de PIB. Nous constatons également que l'intensité nationale des émissions de  $\text{CO}_2$  s'explique par le mix énergétique, la rigueur des politiques environnementales et le niveau technologique. Ainsi, pour expliquer cette relation en forme de U au niveau des pays, nous nous appuyons sur une analyse sectorielle. Les résultats montrent que l'abondance influence différemment l'intensité sectorielle et qu'il existe des effets de contagion entre tous les secteurs (même dans le secteur des services). Il est intéressant de noter que les pays riches en ressources et ceux relativement pauvres en ressources affichent des résultats opposés.

Enfin, ces résultats suggèrent que l'abondance des ressources devrait être une variable clé dans les négociations sur la politique climatique. Sa prise en compte permettrait de mieux cibler les principaux pays à réguler. En effet, plutôt que de se concentrer sur un débat sur les efforts à fournir, qui oppose les pays développés aux pays en développement, il serait plus approprié de regrouper et de coordonner les pays en fonction de leur dotation en ressources naturelles.

### **Chapitre 3: "Revisiting the resource curse: does volatility matters?"**.

Le troisième et dernier chapitre de cette thèse examine si l'abondance des ressources naturelles en soi est une malédiction ou si les effets négatifs observés sur la croissance pourraient être entraînés par la volatilité des revenus issus de l'extraction des ressources naturelles. Il examine également si le développement financier a un rôle à jouer dans la compensation de certains des effets négatifs de la volatilité. Cela est particulièrement important pour les pays abondants en matières premières et pour lesquels les revenus des ressources naturelles sont très volatils.

Nous testons l'hypothèse ci-dessus en utilisant la méthode des données de panel. Notre étude couvre 103 pays sur la période 1985-2015. En plus des modèles standards à effet fixe qui impose encore

un degré élevé d'homogénéité, cette étude empirique est menée en utilisant un modèle non linéaire (PSTR) développée par González et al. (2004). L'approche PSTR est plus intuitive et plus souple que les modèles polynomiaux largement utilisés dans la littérature. Elle permet à l'impact des ressources naturelles, de l'investissement, du capital humain et de la qualité institutionnelle de passer progressivement d'un régime bas à un régime haut en fonction du niveau de volatilité.

Les résultats confirment que, contrairement à la littérature de la malédiction des ressources, l'abondance en ressources naturelles influence positivement la croissance économique. Quant à la dépendance à l'égard des ressources naturelles, elles n'a aucun impact sur la croissance économique. De plus, nous confirmons l'impact négatif de la volatilité des ressources naturelles sur la croissance économique. La perte en terme de PIB peut atteindre 17 points de pourcentage par an entre les pays caractérisés par une faible volatilité de la rente des ressources naturelles et ceux caractérisés par une forte volatilité de cette rente. Par conséquent, nous soutenons que c'est la volatilité, plutôt que l'abondance en soi, qui est à l'origine du paradoxe de la malédiction des ressources.

Finalement, en plus des politiques telles que les fonds souverains, les fonds de stabilisation, un régime de change approprié et la diversification des exportations, nous montrons que les pays ayant un système financier développé peuvent compenser certains des impacts négatifs de la volatilité des ressources naturelles. Par conséquent, l'abondance des ressources naturelles peut être une bénédiction à condition que des politiques de croissance et d'amélioration du bien-être et de développement financier soient adoptées.





# Introduction – English version

## Global context

The industrialization process, which started in the United Kingdom in the mid-18th century, transformed nations forever. The development of modern production and consumption society was only possible thanks to the industrial revolution, which made access for food and clothing available to everyone. The British succeeded in two major revolutions, the agricultural revolution and the industrial revolution. The shift from agriculture to industry raised the employment rate in England through new jobs in the industry. Steam engines also started to be used in the industry, based first on wood and then on coal. The use of coal was a major determinant in the success of the industrial revolution (Behringer, 2010). In 1750, annual coal production was about 5.2 million tons per year in England. By 1870, coal production reached 100 million tons per year – twenty times greater than in 1750 (Behringer, 2010). This huge increase in the extraction of coal participated to the development of industries such as textiles, iron, and chemicals. Between 1870 and 1910, railway construction reached its peak thanks to the use of coal as the main source of supply in the railway networks in England. The use of coal to power steam engines and mechanized textile production spread from England to continental Europe, North America and Japan (Behringer, 2010).

Oil was the second most important fossil fuel after coal during the first industrial revolution. However, the invention of petrol-powered vehicles in 1878 helped oil to become in the long term the leading fossil fuel energy. In 1908, large-scale car production enjoyed new successes with Henry Ford's Model T (Behringer, 2010). This success reached no less than 15 million units of Ford's model, which led the United States to become the largest oil consumer in 1927 (Behringer, 2010). After the Second World War, oil replaced coal in the 1950s because it was cheaper to produce and cleaner to process in a variety of uses. Fossil fuels, from coal to oil, have not only contributed to the success of the industrialization process, they have also led to large-scale urbanization, technological innovations, trade liberalization, wealth accumulation, better-paying jobs and, better

living standards.

Nowadays, countries are reaching higher levels of economic growth through heavy exploitation of natural resources and increasing industrial production. This lead to higher rates of energy consumption and a growing global demand of energy which is expected to grow in the coming decades (population growth, the process industrialization and modernization, urbanization and electrification): according to the World Energy Council (WEC) and the International Energy Agency (IEA), it should increase by 40% by 2035 and double by 2050. At least 80% of the increase should come from developing and emerging countries. Therefore, the supply of energy, which is essential for economic growth and social development, generally is an issue for economists. Especially in countries and regions where energy has historically been scarce and therefore expensive.

Intuitively, a country with an abundance of natural resources should exhibit high levels of growth and vice-versa (Canuto and Cavallari, 2012). According to Emtage et al. (2007), natural resource, once discovered, attracts capital and labor for extraction, processing, sale and transport of the raw materials. Firms are set up to extract, refine and transport natural resource in order to make profit. Other industries grow to and participate to these processes by enhancing job opportunities and revenue generation. Governments are collecting taxes which can be spent on enhancing physical and social infrastructure and human capital. These mineral discoveries acted sometimes as drivers in transforming small villages into large cities, as was the case for Johannesburg and Los Angeles following their respective gold and oil rushes (Petterson, 1951). Therefore, it appears reasonable to assume that economic growth should be driven by the supply of natural resources. The theory of the production function confirms this insight: factors of production (labour and capital) increase sharply following the discovery of natural resources leading to increased production and GDP growth.

However, the empirical evidence of natural resource-poor countries outperforming resource-rich countries is a striking reality. Sachs and Warner (1995) point out that this situation has been repeated on a regular basis. They note that in the seventeenth century, in spite of Spain's inflows of resources from its colonies, it was overtaken economically by resource-poor Netherlands. More recently, Asian Dragons (Korea, Taiwan, Hong Kong, Singapore) which are resource-poor have undergone a rapid industrialization of their economies while many resource-rich economies such as Mexico, Nigeria and Venezuela, have gone "bankrupt" (Sachs and Warner, 2001). Thus, counter-intuitively, endowment in natural resources has become hallmark of regions and countries that have experienced poor economic growth. According to Sachs and Warner (2001), such regions and

countries are said to suffer from the *natural resource curse*.

Moreover, the use of natural resources is not without negative effects. In the recent decades, the rapid increase in anthropogenic greenhouse gas emissions is mostly due to the rush towards better living standards. Industrialization enhances economic growth and the living standards, but it comes with higher level of pollution that threaten our lifestyle. Poor air quality, rising sea temperatures, stronger hurricanes, extreme weather conditions, prolonged droughts, food and water shortage, forced migration and extinction of species are the threats. In comparison to pre-industrial times, CO<sub>2</sub> levels increased by more than 40% relatively to the pre-industrial age. It is mostly driven by industrialization and fossil fuels combustion, according to a report from the Intergovernmental Panel on Climate Change in 2014. Global anthropogenic emissions have continued to grow during the 21st century, with significant increase between 2000 and 2010, relative to any other decade. The same report points out that global emissions of greenhouse gases rose by 31% in 2010 compared to 1990. The combined global terrestrial and ocean surface average temperature during the 21st Century rose by 0.85 Celsius, the snow cover declined by 1.6% per decade. The global average temperature has been predicted to continue to rise, with snow and ice melting and sea levels rising in the 21st century.

These negative environmental impacts have attracted a lot of attention worldwide. The global temperature increase observed in previous decades is mainly due to higher levels of carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) in the atmosphere. Most climate scientists believe that the environment is rapidly deteriorating due to climate change, that is primarily due to human activity, not to events that occur naturally. They show that increasing industrial activity affects living standards and long-term economic growth worldwide. More specifically, there is evidence that poor air quality directly affects human lifespan. Watt et al. (2008) show that chronic health effects and specificity in cause of death are linked to exposure to fine particulate matter (PM<sub>2.5</sub>), using data on 22,902 subjects from the American Cancer Society cohorts. Aunan and Pan (2004) also confirm the serious impact of poor air quality on human morbidity and mortality. As these issues are brought to the public's attention, environmental awareness increases. These challenges have also attracted the attention of researchers in economics, sociology and other areas interested in exploring pollutant determinants and in understanding how society can take action to reduce these effects individually or collectively.

In this context where natural resources can be both a driver of growth and a threat in themselves, this thesis contributes to the debate on the use of natural resources in both economic and environ-

mental dimensions. It falls into four parts: a general introduction and three main chapters that deal distinctly with different aspects related to the use of natural resources. More specifically, two chapters focus on natural resources and economic growth nexus and a chapter on the relationship between natural resources and the environment.

The first chapter is entitled “The actual impact of shale gas revolution on the U.S. manufacturing sector”. It deals with the biggest energy story that has happened in the 21st century so far: the extraction of natural gas from shale rock formations in the United States. We aim to contribute to the debate by identifying and assessing the impact of massive shale gas development on the US manufacturing sector.

The second chapter is co-authored with Mireille-Chiroleu-Assouline and Mouez Fodha, and entitled “Carbon Curse in Developed Countries”. This paper investigates more generally the relationship between natural resources and CO<sub>2</sub> emissions. We aim at assessing whether a country rich in natural resources is more polluting than another country and whether resource abundance affects all sectors of the economy. Our objective is to contribute to the debate on climate change mitigation by measuring the consequences of abundance in natural resources on emissions at different levels: national and sectoral.

The last chapter is entitled “Revisiting the resource curse: does volatility matters?”. While most studies on the so-called *resource curse* paradox look at the negative growth effects of commodity abundance/dependence, they usually, with a few exceptions, overlook the impact of volatility channel. Our main objective is to investigate whether the abundance of natural resources per se is a curse or if the observed negative effects on growth could be due to the volatility of natural resource revenue. Furthermore, we contribute to the literature by examining the channels through which the volatility effect operates, notably investment, human-capital, and institutional quality. This is particularly important for primary-product abundant countries, where resource revenues are highly volatile.

In what follows, we first present a general overview of the content of each part. Next, we present the main contributions of this Ph.D. dissertation by summarizing the aim, the methodology and the results of each chapter.

## Natural resource and development economic

Natural resources are essential to the functioning of human societies and economies. As a primary inputs to most production processes, they supply energy for transport, light and heat around the world. However, natural resources are unevenly distributed across countries. Therefore, they are extensively traded and can strongly influence a country's industrial specialization (Bacchetta et al., 2010). Natural resource management has significant impact on industrial development in the areas of resource production and on the potential for moving towards sustainability.

After the Second World War, OECD countries built their economic development on the use of oil as their main energy source, substituting coal. During the 1950s and 1960s, the rapid economic growth observed in most industrialized countries was based, among other things, on access to abundant and cheap oil. The change in the bargaining power between Western oil companies and oil-producing countries in the 1960s, reflected by the establishment of the Organization of Petroleum Exporting Countries (OPEC), led to the first oil crisis in 1973. This first oil crisis marked the definitive end of the Glorious Thirties, and defeated Keynesian economic theories by inaugurating the phenomenon of stagflation (low growth and inflation) and allowing the emergence of supply theories.

The 1973 oil crisis marked the beginning of a new era. An era of high and volatile oil prices, which will be marked by other oil shocks, the most recent of which was in the year 2000. Prior to this crisis, there had been a growing concern regarding the future limits of growth due, among other things, to the scarcity of natural resources (Meadows et al., 1972). In response to rising concerns about limited resources, energy insecurity and limited growth, the last two decades have seen a significant expansion in the development of alternative, so-called unconventional fossil fuel resources. The picture may have shifted since many industrialized countries may have access to unconventional fossil resources, which could secure their energy supply and make them more affordable to use. The first to start this process are the United States, a pioneer in this field. Therefore, the first chapter of the thesis analyses the impact of the emergence of unconventional resources on US economic activity.

## **The US shale gas revolution**

### **What is it and where it does come from**

The natural gas contained in shale reservoirs has the same primary chemical composition as the natural gas contained in conventional reservoirs, normally up to 95% methane. The main difference is in the geological and physical properties of the reservoirs in which the natural gas is stored rather than the composition of gas itself. Shale gas reservoirs are often classified as 'unconventional' because they contain oil and gas that were generated in the shale itself, and because they do not naturally have sufficient permeability to allow oil and gas to flow at commercial rates. Therefore, shale gas is produced from shales with a technology called hydraulic fracturing (fracking) to create extensive artificial fractures around well bores. Horizontal drilling is used with shale gas wells. Horizontal lengths can reach up to 3000m inside the shale, in order to create a maximum drilling surface. Large quantities of water and chemicals are injected at high pressure to create fissures in the shale and release the natural gas. This latter is recovered from vertical wells. Figure 6 shows schematics of shale gas production.

Shale gas is located in shale "plays" which are formations of shale containing important accumulations of natural gas. They have similar geological and geographical properties. For a decade, production came from the Barnett Shale area in Texas. Barnett shale development experience and knowledge has led to more efficient shale gas production across the US country. A second important play is Marcellus shale in the eastern US. Geologists work to identify suitable well sites with economically recoverable natural gas by using a combination of surface observation techniques and computer-generated maps of the subsurface. Figure 7 shows the location of the different US shale plays.

### **How much is the estimated shale gas resources in the US?**

In the 1970s growing concerns about natural gas scarcity led a number of policy makers and energy companies to direct their efforts toward extracting unconventional gas (Trembath et al., 2012). Three decades later, the production of natural gas decreased slowly despite the rise in the drilling activity. Starting from 2006, the gas industry realized that shale gas is an important and economically exploitable resource that could complement the depletion of conventional gas wells. In 2005, the EIA reported a 6% increase in proven natural gas reserves, the highest rise since 1970. Driven by high gas prices, over 32,000 exploration and development wells were drilled annually

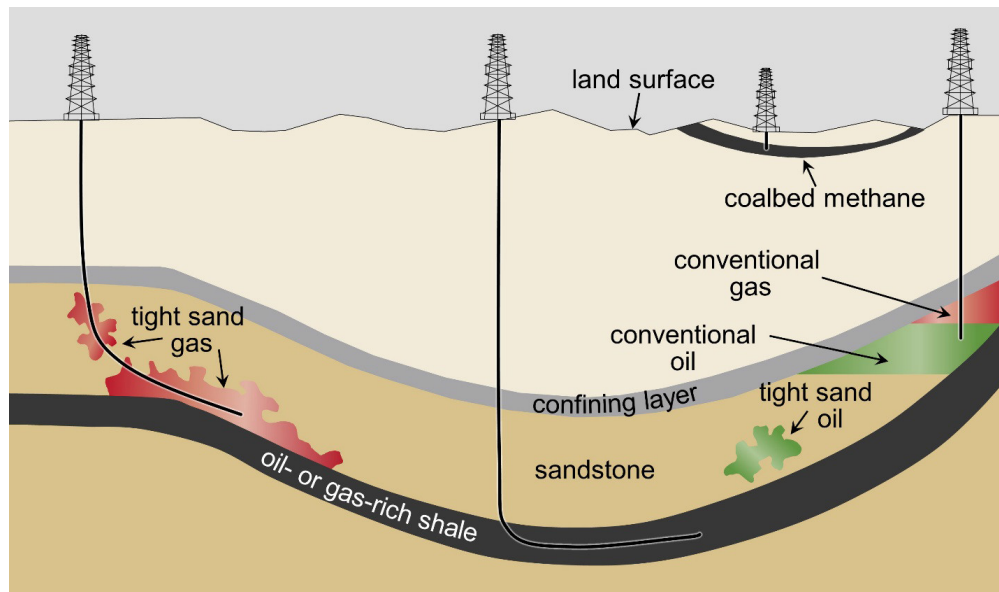


Figure 6: Types of oil and gas wells.

Note: a vertical well is producing from a conventional oil and gas deposit (right). Also shown are wells producing from unconventional formations: a horizontal well producing from a shale formation (center); and a well producing from a tight sand formation (left).

Source: U.S. Energy Information Administration

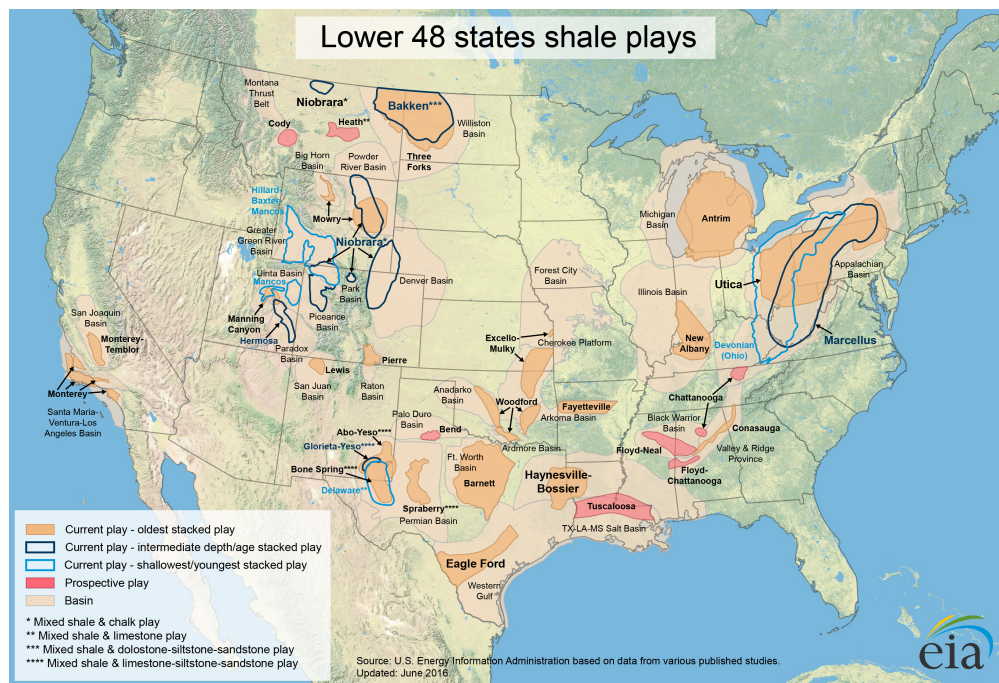


Figure 7: United States Shale Gas and Shale Oil Plays

Source: U.S. Energy Information Administration based on data from various published studies.



between 2006 and 2008. In 2010, proven reserves of natural gas and oil reached the highest levels recorded by EIA since 1977.<sup>7</sup> The United States became the largest producer of natural gas and oil ahead of Russia. This increase has been possible thanks to technological advances that have allowed exploitation of shale gas, which had not been available neither technically or economically before. From 2000 to 2018, the share of shale gas in US natural gas production increased from 1% to 69% and is experiencing constant growth (see Figure 8 and Figure 9). According to EIA forecasts, U.S. dry natural gas production will average 91.4 billion cubic feet per day (Bcf/d) in 2019, up 8.0 Bcf/d from 2018. EIA expects monthly average natural gas production to grow in late 2019 and then decline slightly during the first quarter of 2020 as the lagged effect of low prices in the second half of 2019 reduces natural gas-directed drilling. However, EIA forecasts that growth will resume in the second quarter of 2020, and natural gas production in 2020 will average 93.2 Bcf/d.

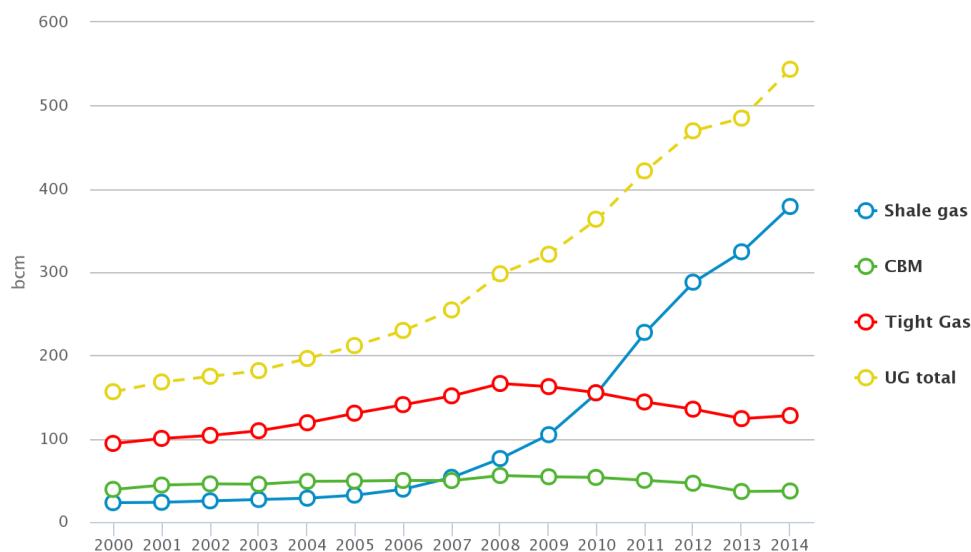


Figure 8: United States natural gas production.

Legend: CBM = Coal Bed Methane; UG = Unconventional Gas. Units: billion cubic metres (bcm).

Source: U.S. Energy Information Administration (EIA).

7. Proven reserves of crude oil increased by 13% (2.9 billion barrels) and proven reserves of natural gas rose by 12% (33.8 trillion cubic feet). Oil reserves at the end of 2010 were 25.2 billion barrels and natural gas reserves at the end of 2010 were 317.6 trillion cubic feet—the first time they reached a level over 300 trillion cubic feet.

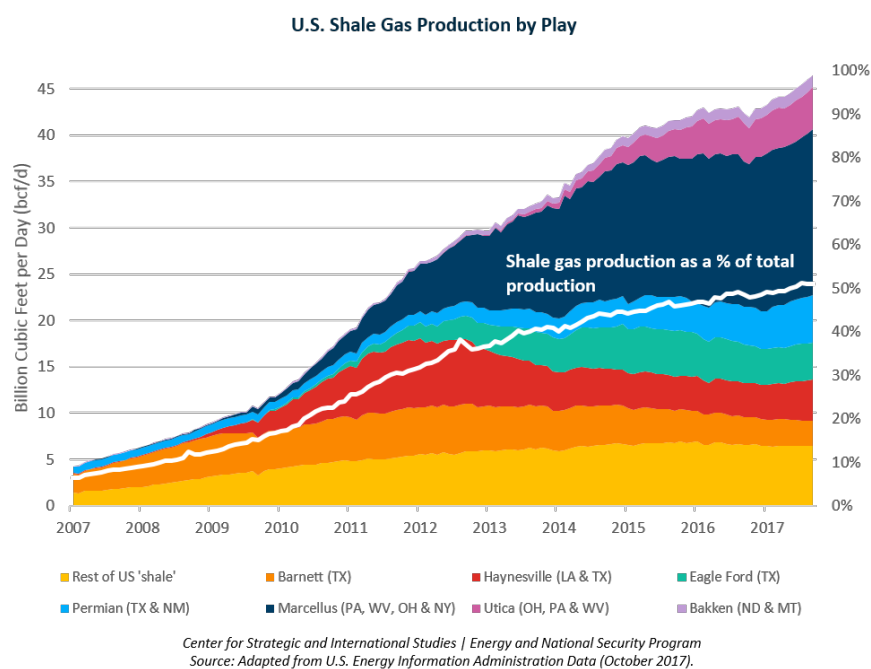


Figure 9: United States Shale Gas Production by Play

### Gas prices and potential effects on manufacturing

Figure 10 shows the increase in total US shale gas production from 2007 onward, as well as the change in the US natural gas price. The increase in shale extraction began in the late 2000s, accelerated in 2010, and amounted to more than 10,000 billion cubic feet by late 2013. As a result of this sustained growth in extraction, natural gas prices in the United States have fallen significantly, while not affecting European gas prices due to the regionalized nature of gas markets. This evolution has allowed the United States to become more competitive vis-à-vis Europe, where the gas price is still largely indexed on oil prices, and is three to four times as high as in the US. In 2012, the price of natural gas in Europe was on average 11.40\$ per MBtu, whereas it was only 2.75\$ per MBtu in the USA (11.10\$ and 3.45\$ respectively in August 2013). The price of imported gas in Europe was thus four times as high as US prices (compared to 2.7 times as high for 2009-2013). These trends have led to prices for European industry which are at least three times as high as prices for US industry, and this difference has widened in the last two years, weakening the position of European industry with respect to the US. The picture is particularly problematic for energy-intensive industries facing international competition, such as chemicals, fertilizers and steel, etc (see Figure 11). As a result of having lower gas prices, the US is an attractive location to industry, in

particular, petrochemical which use huge amount of ethylene. Ethylene is a basic chemical used in thousands of everyday products such as plastic bags, milk cartons, insulation materials, antifreeze, toys and automotive components. It can be derived from crude oil or natural gas (ethane) by various chemical processes. Natural gas of the correct composition is a more efficient feedstock for ethylene production than other hydrocarbon feedstocks; therefore, increased supply has led to a significant drop in ethane prices (see Figure 12).

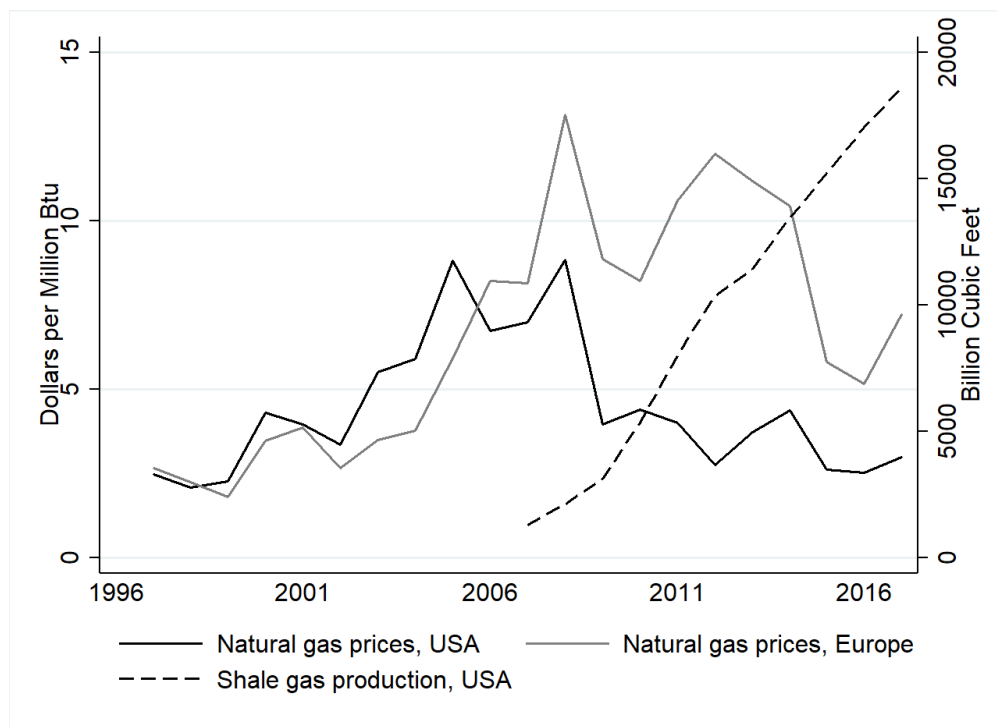


Figure 10: United States natural gas production.  
Source: U.S. Energy Information Administration (EIA)

Finally, the unexpected expansion of the domestic energy supply gives an important economic advantage to US industry, which is leading some economists to talk about the US Manufacturing Renaissance (Wang et al., 2014; Bazilian et al., 2014).<sup>8</sup> Employment in the oil and gas industry increased by 50,000 jobs in 2012, although it was a small share of the 2.2 million of new jobs created if direct and indirect effects are taken into account (Wosepka et al., 2012). In early 2013, the Boston Consulting Group (BCG) predicted that within five years, the United States would experience a rebirth of the manufacturing sector as companies relocated their manufacturing operations in

8. The industrial sector is one of the largest users of natural gas: it includes manufacturing, construction, agriculture and mining activities. It consumed 8.3 quadrillion ( $10^{15}$ ) Btu of natural gas in 2011, about one third of total US consumption. Also in 2011, natural gas accounted for over 40% of energy used in the industrial sector.

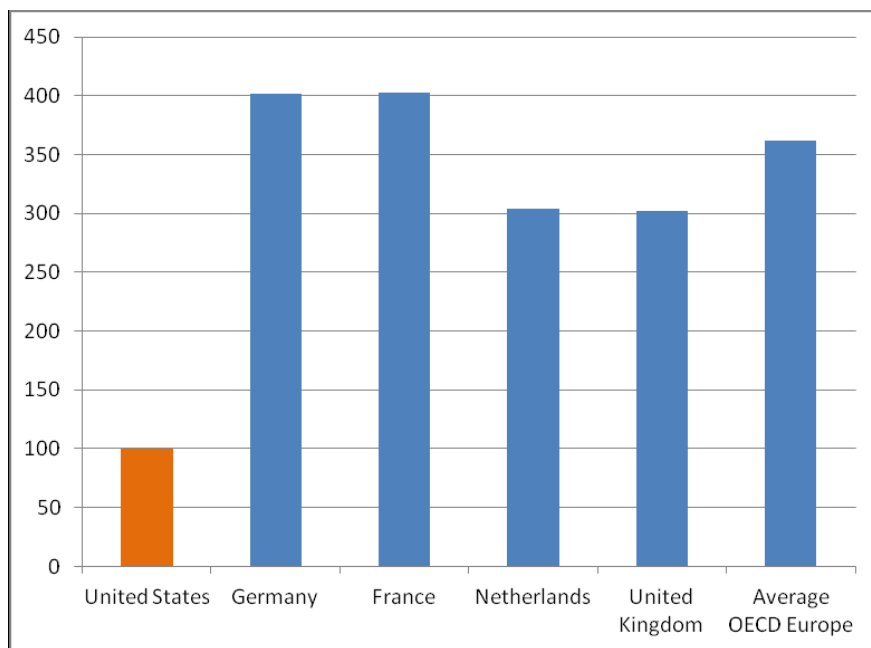


Figure 11: Average Price of Gas for Industry in the United States and Europe (average 2012; indexed prices: the United States = 100).  
Source: International Energy Agency (IEA).

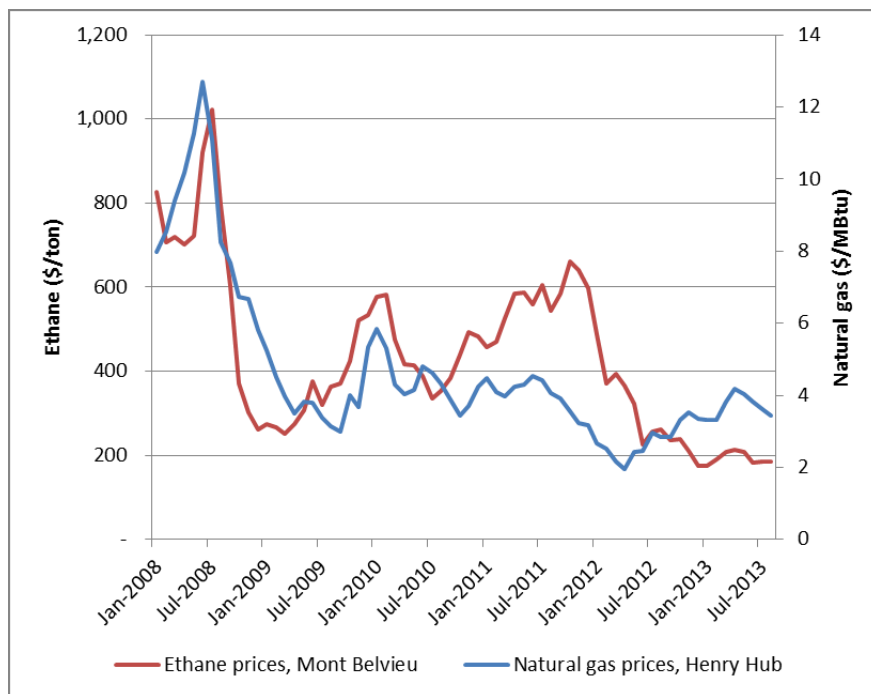


Figure 12: Prices of Ethane and Natural Gas in the United States.  
Source: Platt's, EIA.

USA. The report concluded that the benefits of production cost of goods manufactured abroad have dramatically fallen over the last decade. In 2003, manufacturing costs were 18% lower in China than in the US. In 2011, the difference was only of 7%. Natixis, a French corporate and investment bank, has confirmed that the competitive advantages accruing to US industrial manufacturers through lower gas prices are equivalent to a 17% reduction in wage levels compared to firms belonging to the Euro-zone. Players in the manufacturing industry have congratulated themselves for the gas supply surplus, as it reduces their production costs, thus improving their competitiveness. Cheaper energy also has the potential to create significant employment growth in both primary industries and secondary industries. Other actors see the development of natural gas as an opportunity to use less coal in electricity production and reduce dependence on oil through the liquefaction of gas in the transport sector. Gas producers, meanwhile, saw a great opportunity to benefit by exporting natural gas as liquefied natural gas (LNG).

The discovery of unconventional resources have the potential to boost developed economies that are heavily dependent on fossil fuels from less developed regions. However, what about the impact of natural resources on the economy in countries that are not developed? The recent discovery of significant reserves of oil and gas in East Africa provides opportunity for economic development in the region and fuel the debate about natural resource abundance and growth nexus. Mozambique has found some of the largest natural gas deposits in the world, while Tanzania, Uganda, and Kenya have also discovered gas and oil (Zhang et al., 2019). Exploration is still ongoing, so even more discoveries could be forthcoming. This gives to this region and others a chance to develop their economy. These government expect to receive significant revenues from the oil and gas sector which can be used to implement policies for enhancing economic growth opportunities, promoting sustainable economic development, alleviating poverty and improving standards of living. However, this opportunity is not without risks and challenges often referred to as the resource curse. The following section allows us to lay the basis for a discussion of the resource curse.

### **The Resource Curse Hypothesis: is Natural Resource Abundance Bad for Growth?**

The theory of comparative advantages shows that an endowment of natural resources confers an advantage to one nation over others that results in increased national wealth, all other things being equal. This Ricardian-inspired assumption is hardly supported in practice. The income gap between rich and resource-poor countries between 1960 and 1990 widened in favor of the resource-poor. Indeed, too much dependence on natural resources has been frequently linked to

poor macroeconomic performance and growing inequality. The topic has been an important research area. However, little consensus exists on the effect of natural resource richness on economic growth and the mechanism underlying the effect. A number of transmission channels have been identified in the literature in order to describe the curse that was highlighted by Sachs and Warner (1995). These channels can be divided into two different but overlapping categories: economic and political explanations.

The Dutch diseases theory is the first modern economic interpretation of the resource curse. The models developed by Corden and Neary (1982) and Van Wijnbergen (1984) highlight how new discovery of natural resources in a country can affect negatively national income by hurting learning by doing mechanisms in the production sector. The new discoveries drive up the salary due to the increasing demand for workers in the extraction sector. As a consequence there is a shortage of work and higher input costs in the manufacturing sector. In addition, an increase in mining revenues leads to higher spending in non-traded goods, such as construction and services. Prices of non-traded goods and services rise, resulting in a real exchange rate appreciation. As a result, economic growth is slowing as manufacturing output and exports of non-commodity decrease, due both to higher labor costs and higher real exchange rates that make exports of non-commodity goods more expensive and less competitive. Another economic channel through which natural resource may harm growth is natural resource price volatility. In endowed natural resource rich country, the extractive industry represents the primary source of income. Due to high fluctuation in commodity prices and the over weighted share of the primary sector, the governments' ability to properly manage their public finance budget is hindered. Moreover, the macroeconomic instability that results from resource price volatility can also discourage investment (Van der Ploeg and Poelhekke, 2009). Indeed, natural resources are known to exacerbate macroeconomic volatility (Bleaney and Halland, 2009; Malik and Temple, 2009; Frankel, 2010), while empirical studies confirm a negative relationship between volatility and growth (Aizenman and Pinto, 2004; Loayza and Hnatkovska, 2004; Ramey and Ramey, 1994).

Now we turn to the political channels of the resource curse, or the "political Dutch disease" as it is called by Lam and Wantchekon (2003) which address governance issues. According to Sachs and Warner (2001), Hodler (2006) and Iimi (2007) natural resource revenues in some countries increase the power of elites, who have the power to increase income inequality and therefore harm income level. The other main political channel is the weakness of institutions as a key determinant of the resource curse (Arezki and van der Ploeg, 2010; Robinson et al., 2006). Indeed, natural resources may have a negative impact on institutions: resource-rich countries are prone to have centralized

government with collusion between governments and the mining industry. Tornell and Lane (1999) consider that weak institutions are to blame for the slow growth recorded in Nigeria, Mexico and Venezuela after the discovery of oil in these countries. Sala-i Martin and Subramanian (2013) found that the corruption that emerged after the discovery of oil was responsible for Nigeria's slow growth. Finally, citetmehlum2006institutions also states that good institutions are essential to solving the resource curse.

Empirical results about the paradox of the natural resource curse are mixed. Rodriguez and Sachs (1999); Gylfason (2001) and others confirm the results of Sachs and Warner on the adverse effect of the level of resource abundance on economic growth. However, Brunnschweiler and Bulte (2008) states that the resource curse is no longer valid when the correct measure of resource abundance (rather than dependence) is used in regressions. In addition, Smith (2015) assesses the impact of major oil discoveries since 1950 on GDP per capita. Using various quasi-experimental methods, such as the synthetic control method, he finds that oil discoveries have a positive impact on long-term growth.

The governments in many resource-rich countries face two important and related challenges with regard to the resource rents: How much of the resource rents should be spent or saved? How to spend the revenues? The resources are exhaustible, the rents are affected by the fiscal regime, vary with global energy prices and the rate of resource extraction. Resource-rich developing countries must define their goals and take decisions toward sustained growth and poverty reduction.

Finding solutions to these challenges requires understanding the type of resource endowment, as well as technical aspect and the global economic situation of a country. Indeed, types of reserves (gas vs oil), quality of crude oil or natural gas, and the technical challenges to production (depth level, onshore vs offshore) affect the costs associated with extraction of the resource, and therefore, the expected rates of return for the oil company and the government's fiscal receipts. The level of tax rates and the types of fiscal instruments (royalties, cost recovery limits, corporate taxes, depreciation allowances, etc.) affect the ultimate exploitation of the natural resource and the time profile of the extraction (Petty et al., 2015). These may impact not only the extraction time profile of the resource, but also the distribution of resource rents among the stakeholders.

Finally, thanks to Shell and BP, along with the majority of other oil companies, growing investments in exploration and development of new fields, both conventional and non-conventional, creates opportunities for further development. Simultaneously, the combination of economically recoverable unconventional to conventional reserves more than double the amount of carbon that could be

released into the atmosphere. However, to prevent an irreversible change in climate and its negative impacts, a total limit of 500 billion tonnes (gigatonnes or Gt) of carbon emitted into the atmosphere is required. We have already released 370 Gt since the beginning of the industrial revolution, which leaves a limit of 130 Gt that could be added. Therefore, the recent development of non-conventional fossil fuels and their potential carbon foot print is incompatible with being under 500 Gt limit. These increasing discoveries is a real threat for the mitigation of the climate change. Moreover, given that the connection between growth and emissions is still very much debated (EKC), can we finally question whether the issue of emissions is completely disconnected from that of the ownership of resources? Is having a resource that is available, which is often cheaper than for importing countries, not have side effects on energy efficiency efforts, national decisions regarding energy mix and climate change mitigation? The following section allows us to lay the basis for a discussion of the carbon curse theory.

### **Natural resource and climate change**

Energy consumption and greenhouse gases emissions become key concerns following increasingly alarming observations on climate change. In September 2013, the Intergovernmental Panel on Climate Change (IPCC) met in Stockholm to present its results, which harden its previous findings. Global warming is accelerating. The land and ocean surface temperature has been increasing by  $0.85^{\circ}\text{C}$  in average since 1880. The IPCC forecasts an increase in temperature from  $0.3^{\circ}\text{C}$  to  $4.8^{\circ}\text{C}$  for this century depending on the scenario. Such an increase would have a non-negligible impact on the number of extreme climatic events. For example, 2012 was among the 10 warmest years on record. This caused several unusual climatic events, such as the lowest recorded levels of Arctic sea ice (97% of the Greenland ice sheet showed some forms of melt Swindles et al. (2013), Hurricane Sandy in United States, the heavy rain in northern Europe and eastern Australia.

First, natural disasters caused a number of human fatalities, counted in 2012 at approximately 8,800. This represents the fewest number of victims related to climatic events since at least 2002. Second, besides human fatalities, damages related to natural disasters represent a very high cost. Events that occurred in 2012 represent an economic loss of 200 billion and an insured loss for the population of 72 billion (Benfield, 2014). Hurricane Sandy was the costliest event of the year and accounts with the drought in U.S. for the half of economic losses. This is not an exceptional cost: 2012 was the fifth costliest year in term of economic losses since 2002. Third, all consequences of these climatic changes are not observable today. The level of sea will continue to increase



following the rise of temperature, and this would increase the frequency and worsen the intensity of events such as storm and flooding. The Sustainability (2011) report stresses the fact that the environmental degradations or habitat destruction could threaten development and increase poverty in emerging countries. In this report, the impact of climatic events on Human Development Index (HDI) is estimated, taking into account several scenarios. The ‘environmental challenge’ scenario captures the adverse effects of global warming on agricultural production, on the access to clean water and improved sanitation, and on pollution. The ‘environmental disaster’ scenario features vast deforestation and land degradation, dramatic declines in biodiversity and accelerated extreme weather events. Simulations suggest that the global HDI would be 8% lower by 2050 in the ‘environmental challenge’ scenario, and even 12% lower for south Asia. The ‘environmental disaster’ scenario predicts a global HDI 15% below the baseline. Several mechanisms play a role. The same report shows that climatic events, as the droughts in Africa and the sea level rise in low-lying countries like Bangladesh, could lead to an increase of the world food price from 30 to 50%, affecting first the poorest countries.

Given the dramatic implications, there is broad consensus today on the need for international community to address the problem of climate change. The fight against climate change began with the discussions at the United Nations Conference on the Environment in Stockholm in 1972. Twenty years later the United Nations Framework Convention on Climate Change (UNFCCC) was put in place to negotiate the reduction of greenhouse gases emissions. Thanks to the UNFCCC, the first international agreement which is The Kyoto Protocol was adopted on 1997 in Japan. It sets out legally binding emission commitments and market mechanisms that enable industrialized countries to mobilize the most cost-effective global mitigation solutions. In accordance with the Kyoto Protocol, most developed countries committed themselves to a 5% overall decrease in their greenhouse gas emissions by 2012 in comparison to the level of 1990. This international cooperation continue with the recent Paris Climate Agreement which define a new binding climate agreement for all countries. It limits the global average temperature increase to  $1.5^{\circ}C$  above pre-industrial levels. However, such targets can only be achieved if countries agree to reduce emissions from fossil fuels combustion, as emissions from these sources lead to a significant increase in greenhouse gases.<sup>9</sup>

With a growing global population, competition and environmental problems facing countries, it is important for countries to switch from fossil fuels to cleaner energy sources in order to meet their

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9. Fossil fuels accounted for 84% of the world’s energy consumption in 2012, and approximately 2/3 of global greenhouse gas emissions is due to the energy supply and use of fossil fuels.

rising energy demand. One of the future challenges of our society is to maintain economic growth while maintaining or building up Earth's natural capital. A strand of the economic-energy research literature focuses on this, i.e. decoupling environmental degradation from economic growth. There are two types of decoupling: relative and absolute. Relative decoupling implies that emissions grow slower than the economic growth. Absolute decoupling implies that emissions decline while the economy grows (Giorgetti, 2007). Some researchers argue that decoupling is a “natural” process that automatically happens when economies grow. Others argue that it is political actions that are the main reason for bringing down emissions and environmental degradation (Persson et al., 2006).

### **The Environmental Kuznets curve**

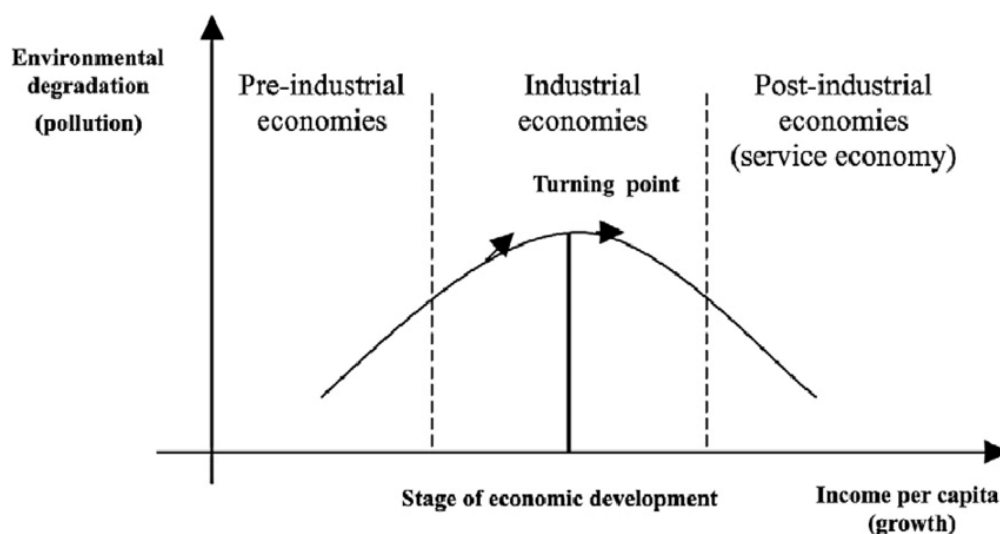
To achieve a healthy balance between economic growth and environmental protection, a significant shift in our energy consumption patterns is needed on a global scale. Over the past three decades, the connection between economic growth and environmental pollution has sparked great interest. Grossman and Krueger (1991) introduced the idea of the Environmental Kuznets Curve (EKC) in a paper for a conference on North American Free Trade Agreement (NAFTA).<sup>10</sup> Essentially, Grossman and Krueger (1991) investigated the evolution of the production of sulphur dioxide, smoke and suspended particulate matter from industrial areas of 12 countries. They find that for two pollutants (sulphur dioxide and smoke), concentrations increase with GDP per capita at low levels of national income, but decrease as income levels increase. Their findings are particularly interesting to economists and policy analysts due to their importance in policy implementation. Indeed, if the relationship assumed appear to be valid for all countries, instead of constituting a threat to the environment, economic growth is the means by which sustainable economic development may be achieved, as depicted in Figure 13 below:

The question whether environmental degradation is increasing or decreasing with economic development has been investigated for a broad range of pollutants, such as lead emissions from cars, deforestation, greenhouse gas emissions, toxic waste and indoor air pollution.<sup>11</sup> Several econometric approaches were used to examine the relationship, covering higher-order polynomials, fixed and random effects, splines, semi-parametric and non-parametric techniques, as well as different interaction models and exponents. The conclusion is that the turning points differ from one country to another. For some countries, turning points are at the highest income level, or even no turning

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10. A clause in the NAFTA assumes that there will be a cross-border transfer of environmentally challenging production from the US and Canada to Mexico.

11. These indicators have turned out to be the most commonly used approximation of environmental quality.



Source: Panayotou (1993)

Figure 13: The Environmental Kuznets Curve.  
Source: Panayotou (1993).

point at all. For other pollutants, it seems to increase steadily with income. Actually, the empirical evidence is rather mixed.

Theoretically, there are several studies that explain the relationship of income and pollution. There are two different approaches regarding this relationship: the first argues that economic growth is damaging to the environment (Meadows et al., 1972), while the second argues that technological process and economic growth improve the environmental quality (Panayotou et al., 1993; Brock and Taylor, 2005). According to Brock and Taylor (2005), the higher the growth of an economy, the greater the development of all activities, and the higher level of pollution. But as economic activity shifts from energy-intensive industries to cleaner industries, emissions decrease due to the compositional effect and, as investments in clean technologies become more efficient, sustainable development is achieved. Arrow et al. (1995) also state that environmental conditions tend to deteriorate in the early stages of economic development, whereas when societies reach advanced stages, they tend to pay greater attention to environmental quality through market mechanisms and regulation policies. However, these authors warned against reading the EKC as suggesting that the national and international environmental issues would be tackled through country-specific autonomous processes. Besides, Lopez and Mitra (2000) shows that the EKC can be explained in terms of the preferences of economic agents. He argues that if the preferences are homothetic, higher incomes result in higher consumption, which in turn translate into higher production and, ultimately, higher pollution level. But if preferences are no longer homothetic and incomes increase,

people may want to consume less and therefore pollute less, depending on their relative risk aversion between consumption and environmental quality. Another theoretical approach supporting the EKC assumes the environment is a luxury good, which means that if revenue increases by 1%, the demand for environmental quality increases by more than 1%. Using a sample of European Union (EU) countries, McConnell (1997) shows that environmental quality is a normal good with an income elasticity of demand slightly below one.

As explained above, several studies have examined the relationship between economic growth and environmental quality. They used a range of environmental indicators, countries, regions, sectors and advanced econometric techniques. However, the results are far from providing a definitive answer. The discrepancy in the results can be attributed to several factors, such as, the type of data used and the methodology applied. There are also other factors that can modify the nature of this relationship, such as the degree of economic liberalization, environmental regulations within the country, historical land development, and the impact of weather conditions. Therefore, not accounting for such variables in the relationship analysis may distort the trajectory of pollution relative to income. Given these limitations, some researchers have been cautious in interpreting the results and have started to call for mitigation measures through regulations (Dasgupta et al., 2002).

### **Climate mitigation: from classical cleavage of developing versus developed countries to resource-rich versus resource-poor countries**

Natural resource-rich countries are a neglected category in current policy debates on climate change mitigation. So far, these debates have largely gravitated around the cleavage of developed versus emerging economies. What has been overlooked is the cross cutting cleavage of natural resource-rich versus natural resource-poor countries. In resource-poor economies, the logic of resource-scarcity constrains carbon intensity. In resource-rich economies, by contrast, the logic of resource-abundance produces the opposite effect. Therefore, resource-rich countries require special attention. A better awareness of fuel rich economies and the obstacles they must overcome to keep their carbon intensity within acceptable bounds is necessary. Investigating the role of resource rich countries will help to steer the climate debate in a more productive direction and to gain a balanced and comprehensive picture of the fundamental challenges that make it so difficult to reduce overall global CO<sub>2</sub> emissions.

## Some proof of the carbon curse

The *carbon curse* theory links a country's fossil fuel endowment with the carbon intensity of its economic output. Its main assumption is that a country's fossil fuel endowment drives its carbon intensity, and that it is difficult for fossil-fuel rich countries to prevent this from happening.

To illustrate the overall relationship between natural resource abundance and energy intensity, Figure 14 from Friedrichs and Inderwildi (2013) ranks countries by increasing CO<sub>2</sub> intensity (per unit of GDP). The highlighted countries are rich in resources.<sup>12</sup> Among the twenty countries with the highest CO<sub>2</sub> intensity, eighteen are resource-rich countries (highlighted in red and blue). A significant positive relationship can be easily seen in this figure. However, correlation itself is not a causal relationship. A typical situation emerges, such as resource-rich countries with low CO<sub>2</sub> emissions (Norway, Nigeria, Angola, Ecuador). The impacts of natural resource abundance on CO<sub>2</sub> intensity remain unclear.

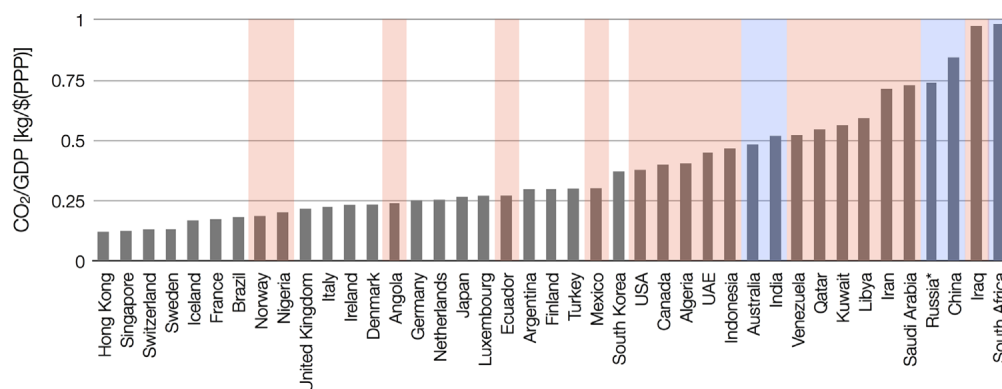


Figure 14: National carbon intensities in 2008. Oil-rich countries marked in red, coal-rich countries in blue.

Source: <http://data.un.org>.

Figure 15 from Friedrichs and Inderwildi (2013) shows the decarbonization process of countries between 1996 and 2008. They are divided into three categories: emission reduction (green), emission increase (yellow) and emission intensification (red). In the upper left panel, all the countries of the sample are shown, while the other three panels have specific subgroups; the twenty leading industrial countries (G20), the fifteen most advanced high-tech economies as defined by the Global Competitiveness Report (Schwab, 2012) and the twelve OPEC members. We observe that seven countries succeed in decarbonizing faster than their economies were growing, resulting in an abso-

12. Oil-rich countries marked in red, coal-rich countries in blue.

lute reduction in CO<sub>2</sub> emissions (green zone). Except for the UK, they are all highly developed, technically advanced and fuel-poor. Conversely, countries that have experienced a massive increase in carbon emissions (red zone) due to accelerating economic growth and increasing carbon intensity share the following characteristics: they are all major oil or coal producers and, with the exception of Norway, members of the Organization of Petroleum Exporting Countries (OPEC). Between these two, the yellow areas represent countries that have successfully reduced their carbon intensity, but have still experienced absolute increases in their carbon emissions due to higher economic growth rates. The group consists of the world’s largest economies such as China, the United States and India.

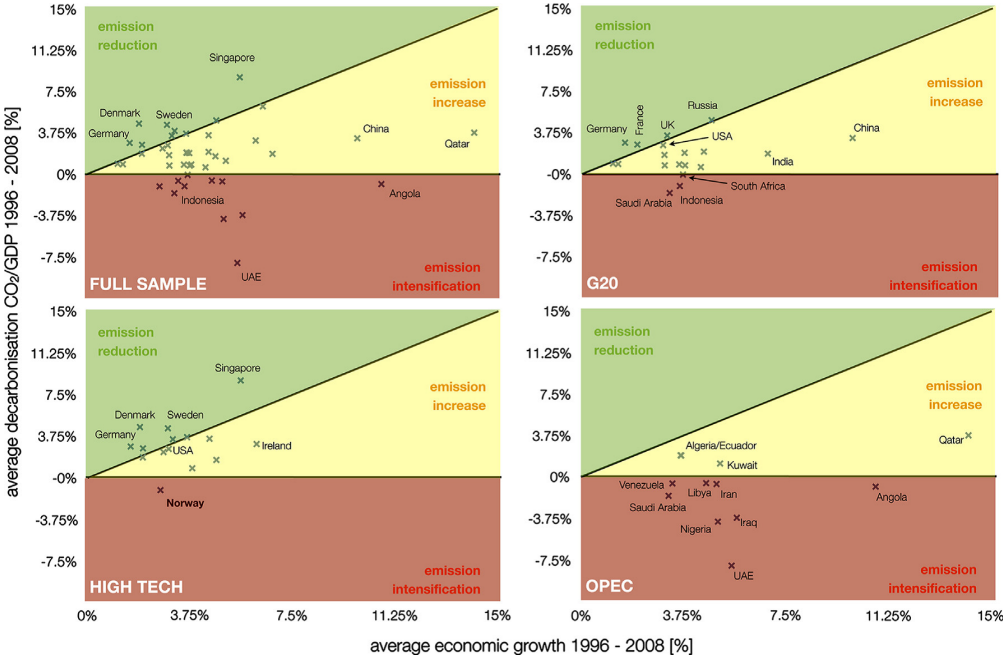


Figure 15: Carbon trajectories represented by the average annual increase or decrease in carbon intensity against average economic growth rates between 1996 and 2008. Source: <http://data.un.org>.

Beyond this observation by Friedrichs-Inderwildi (2013), it is important to analyse in depth the factors that determine the link between abundant natural resources and CO<sub>2</sub> emissions. The next section presents in more details the contributions, aims, the methodology and the results of each chapter.

## Contributions

### Chapter 1: "The actual impact of shale gas revolution on the U.S. manufacturing sector".

This paper aims to provide a clear assessment of the impact of the production of shale gas on the US manufacturing sector. To do so, it assesses the impact on industrial production, investment, employment, import and export variables of the price difference of natural gas between the US and Europe, using annual data for a group of 80 industries for the period 1997-2013. The use of gas prices to estimate the effect of shale gas is justified by the positive supply shock which occurred in 2006 in the US gas market due to the massive exploitation of shale gas (Wakamatsu and Aruga, 2013; Aruga, 2016; Caporin and Fontini, 2017). Therefore, US gas prices have moved downwards since 2006. The construction of the variable measuring natural gas prices of the United States compared to the European prices will capture the comparative advantage conferred to US manufacturing. The first contribution of this article is to build an "energy intensity" variable from the MECS (Manufacturing Energy Consumption Survey) survey conducted in 2006. Indeed, this variable gives a precise indication of the industries that are more likely to profit from the drop in gas prices, since it gives information on gas and energy consumption levels close to the date of the positive supply shock on the US gas market. Then, multiplying this ratio of prices by the energy intensity of each industry allows a new proxy to be constructed, which is more relevant. It distinguishes the advantage of the various sectors according to their energy intensities. Indeed, the new proxy provides a two-fold benefit. The first one is to obtain a measure of sectoral comparative advantages. The second advantage is econometric, as the new proxy creates more variability in the data, which improves the efficiency of the estimators used. Second, since the natural gas price dropped sharply since 2006, we test for a hypothesis of structural break in the relationship between our five variables and natural gas prices, and find structural breaks only for imports and exports. Finally, we estimate dynamic panel data which allows to compute the short and long term elasticities.

The results indicate that the decline in natural gas prices in the US relative to the price of natural gas in Europe has led to an increase in industrial activity and investment of nearly 3%, for the whole manufacturing sector. By taking into account for structural breaks, we find that export increases by nearly 1% while import decrease by nearly 1%. As for the sectoral impact, there is a

significant disparity. Indeed, industrial activity in the most intensive sector reacts to the decline in gas prices by an increase of at least 30%. Finally, even if some industries are expanding, this does not seem to have a great effect on the whole manufacturing sector till now. These results should be interpreted with caution given that firms adjust their production processes only gradually.

Finally, in a world where the growth and sustained development matters now more than ever, shale gas may be a key player in the transition path between nowadays energy mix and hopeful future that would chiefly involve renewable energy sources. On top of the direct effect on climate change, implementing such policy would also increase the overall effect of shale gas exploitation on US manufacturing sector and may lead to the renaissance of the whole manufacturing sector. Perhaps the overall effect of this energy boom is still to come and has not yet been realized.

## **Chapter 2: "Carbon Curse in Developed Countries" co-written with Mireille Chiroleu-Assouline and Mouez Fodha.**

The second chapter seeks to empirically investigate whether a country rich in natural resources is more polluting than another country and whether natural resource abundance affects all sectors of the economy. Our objective is to contribute to the debate on climate change mitigation by measuring the consequences of abundance in natural resources on emissions at different levels: national and sectoral. The relationships between resources and economic growth have already been widely discussed in the literature. Studies conclude that there are links between natural resources and economic growth (resource curse) and interactions between pollution levels and economic growth (the Environmental Kuznets Curve). Our work is at the crossroads of these two fields since we investigate more generally the relationship between natural resources and CO<sub>2</sub> emissions to test the carbon curse assumption. To the best of our knowledge, this study is the first to go beyond a simple descriptive statistical analysis by proposing econometric tests of the carbon curse assumption.

The main intuitions for the mechanisms at stake for a carbon curse are as follows. First is a composition effect induced by the predominance of fossil fuel sectors which massively emit CO<sub>2</sub>. Second are the crowding out effects in the energy generation sector, which forms a barrier to the development of renewable energy sources. Third are the spillover effects in other sectors of the economy, which are combined with less stringent policies. Therefore, to deeply analyze the interactions between natural resources and pollution, we consider both macroeconomic and sectoral data for a group of developed countries. Our database includes 29 countries, including the BRIC, and



spans over 15 years (1995–2009); it reveals considerable heterogeneity between the countries. Our sectoral data consider seven sectors. This magnitude of data, both geographically and temporally, makes it possible to measure the complexity of the carbon curse hypothesis better. The results show that the interaction between CO<sub>2</sub> intensity of GDP and resource abundance is non-monotonous. More specifically, our results show that there is a U-shaped relationship between CO<sub>2</sub> intensity and resource endowment at the country level: above a turning point, the more natural resource-rich a country is, the more it will emit CO<sub>2</sub> per unit of GDP. We also find that national CO<sub>2</sub> intensity is explained by the energy mix, environmental policy stringency, and technological level. Thus, to explain this U-shaped relationship at the country level, we rely on a sectoral analysis using sectoral CO<sub>2</sub> emissions intensity. The results show that abundance has a different impact on the sectoral CO<sub>2</sub> intensity across sectors and that there exist spillover effects among all sectors (even in the services sector). Interestingly, resource-rich and relatively resource-poor countries show opposite results.

Finally, these results suggest that resource abundance should be a key variable in climate policy negotiations. Taking it into account would make it possible to target the main countries to be regulated better. Indeed, rather than focusing on a debate on the efforts to be made, which pits developed countries against developing countries, it would be more appropriate to group and coordinate the countries according to their natural resources endowment.

### **Chapter 3: "Revisiting the resource curse: does volatility matters?"**

The last chapter of this thesis examines whether the abundance of natural resources per se is a curse or if the observed negative effects on growth could be due to the volatility of natural resource revenue. It also investigates whether there is a role for financial development in offsetting some of the negative effects of volatility. This is particularly important for primary-product abundant countries, where resource revenues are highly volatile.

The results of the literature remain mixed, whether natural resource abundance or natural resource dependence causes the resource curse. Furthermore, all these studies generally focus on the effects of either natural resource abundance or natural resource dependence as natural resource wealth indicator on economic growth. Indeed, there is hardly any study, which looks into the individual effects of both indicators. Therefore, the first contribution of this paper to the literature is to

investigate the direct effect of natural resource abundance and dependence on growth. Secondly, we assess the indirect effect of natural resources on growth performance via natural resource revenue volatility. Furthermore, we contribute to the literature by examining the channels through which the volatility effect operates, notably investment, human-capital, and institutional quality.

Methodically, we test the above hypothesis using panel data covering the period 1985–2015 and 103 countries. The use of panel data is a significant departure from most existing studies on the resource curse, which typically present results driven by cross-country variation. In addition to the standard fixed effect methodology which still imposes a high degree of homogeneity, this empirical study is conducted using the panel smooth transition regression (PSTR) approach recently developed by González et al. (2004). The PSTR approach is a more intuitive and flexible methodology than the polynomial models widely used in the literature. It allows the impact of resource rent, investment, human capital and institutional quality to smoothly move from one regime to another depending on the value of a threshold variable (here, volatility of resource rent).

The estimation results confirm that, in contrast to the predictions of the resource curse and Dutch disease literature, a higher natural resource abundance significantly raises economic growth while a higher resource dependence have no impact on economic growth. In addition, our empirical findings also reveal a significant negative effect of resource rent volatility on output growth. Indeed, GDP growth loss may reach 17 percentage-point per year between countries characterized by low natural-resource rent volatility and those by high natural resource rent volatility. Therefore, we argue that volatility, rather than abundance per se, drives the resource curse paradox. We also find that two operating channels of the resource curse are human and physical capital. Furthermore, using data on financial development, our results illustrate that a better financial development can offset some of the negative effects of rent volatility.

Finally, as several channels may lead to harmful effects, it is essential that each resource-rich country has in place policies adapted to its characteristics and situation to limit these negative impacts. In addition to policies such as sovereign wealth funds (SWF) as well as stabilization funds, a suitable exchange rate regime, and export diversification, we show that countries with developed financial development can offset some of the negative impacts of rent volatility. Consequently, resource abundance can be a blessing provided that growth and welfare enhancing policies and financial development are adopted.



# Chapter 1

## The actual impact of shale gas revolution on the U.S. manufacturing sector

YASSINE KIRAT<sup>1</sup>

### 1.1 Introduction

Energy supply remains a major issue on the 21st century. Among energy sources, fossil fuels hold a prominent place and they will still meet 87 percent of energy needs in 2025, though natural gas is the only source of energy for which global demand is forecast to grow in all scenario.<sup>2</sup> Natural gas is now positioned as a major issue and appears as an alternative to other sources of energy due to its abundance and lower polluting capacity (Hu and Xu, 2013; Maya, 2013). In the US, from 2000 onwards, the production of natural gas decreased slowly despite the rise in the drilling activity. The falling supply led to higher prices in the US market, which was met by a drive to import liquefied natural gas (LNG) from Trinidad and Tobago (Gaul and Platt, 2007). Meanwhile, shale gas operations developed gradually, and represented only 1% of the total natural gas production in the US in 2000. At the time, there was no hope that changes in unconventional natural gas production could bring opportunities for enhancing security of supply in the US market. However, unexpected technical advances associated with two existing extraction techniques – horizontal drilling and hydraulic fracturing – have allowed the massive extraction of shale gas to emerge as a resource,

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2. U.S EIA, Annual Energy Outlook 2015.

from 2006 onwards. This development has offset the depletion of conventional natural gas. In 2013, shale gas represented about 40% of the total natural gas production in the US.<sup>3</sup> This positive supply shock lead North America to be ranked as the second region with the lowest costs for energy and raw materials in the world, after the Middle East (Cornot-Gandolphe, 2013). This achievement of the US has caused heated debate about shale gas worldwide, particularly in Europe. The supporters of shale gas highlight the outlook for economic growth and reduction in energy imports dependency. Opponents point to the clear danger for the environment due to the hydraulic fracturing process (Vengosh et al., 2014; Rahm et al., 2013). In France, the opposition to shale gas led to a law in 2011 which prohibits any activities related to its exploration or extraction. France therefore faces a completely contrasting situation to the US. It should be noted that, similar bans exist in the U.S. as well, for instance in the state of New York, with somewhat weaker restrictions in a number of other states. In this context, the present study aims to contribute to this debate by identifying and assessing the impact of massive shale gas development on the US manufacturing sector.

Despite controversy and a lack of definitive answers on its likely negative impact on environment, the expansion of the gas industry has undeniably provided a windfall to the US economy in multiple dimensions (Kinnaman, 2011). Indeed, three effects are observable: a direct effect, an indirect one and a competitiveness effect. The direct effect captures changes in the economic activities of oil and gas extractive industries, as employment increases in mining areas. The indirect effect relates to upstream sectors of the industry, such as suppliers who take advantage of increased demand due to investments in oil and gas extractive industries. These mainly include metal industries and industrial processes: as US Steel for steel production, Vallourec preparing a new steel pipe plant in Ohio or TMK IPSCO developing its search abilities for the extraction of shale gas.<sup>4</sup> Finally, the downstream effect corresponds to changes in economic activity in industrial sectors that benefit from lower prices of energy input (natural gas in this case). These prices decreased by 70 percent from 2008 to 2012.<sup>5</sup> Indeed, the fall in energy prices has enabled companies to reduce their costs of production, which increases the competitiveness of manufacturing sectors, especially those that are the most energy intensive.

The boom in the production of oil and natural gas in the United States has generated a plethora of comments and analysis. A large majority of these studies are purely descriptive for the impact at the macro level (Gas, 2011; Maya, 2013). Nevertheless, some authors have tried to quantify the economic impact of this boom.

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3. U.S EIA, Annual Energy Outlook 2015.

4. <http://www.bloomberg.com>.

5. U.S EIA, Annual Energy Outlook 2014.

A first strand of the literature analyses the impact of shale gas exploitation on the US economy using a computable general equilibrium model. Houser and Mohan (2013) conducted an in-depth analysis to compute the new production costs for US manufacturing industries, considering the decline of oil and natural gas prices through to 2035. Between 2013 and 2020, they estimate that the oil and gas boom could lead to a cumulative 2.1 percent increase in economic output. Based on these low costs effects, they argue that relatively few industries will benefit from a substantial competitive advantage. The IMF published a study in 2013 that assesses the impact of the oil and gas energy boom on the economy. The results show an increase of 0.5 percent of GDP over the coming decade, which is qualified as positive but still modest. Morse et al. (2012) provide an initial impact to quantify the downstream outcomes of the shale gas boom. This boom will lead to an increase of 1.1 million jobs in manufacturing by 2020, a 9 percent increase compared to the scenario without the energy boom. They also find that the real GDP grows by 0.2 percent above baseline by 2020. This implies a 1.6 percent increase in manufacturing production, which accounted for 12.5 percent of GDP in 2012. The overall effect seems as modest as the IMF results.

General equilibrium models are based on assumptions of general equilibrium of all markets, in order to study the impact of shale gas by using the parameter calibration technique (based on past periods). Drawing on a different approach, this paper uses real data to estimate the effect of the shale development and contributes thus to the second strand of literature on empirical models of trade flows and trade policy.

Celasun et al. (2014) use the cross-country panel data to estimate the response of the manufacturing sector's output, considering changes in relative natural gas prices (domestic vs. world average) for the period 2001-2013. According to their results, if the natural gas price differential is multiplied by 2 in favor of the home country, manufacturing industrial production will increase by 1.5 percent. Sendich (2014) explores the direction of causality between gas prices and manufacturing output to see whether gas prices are a determinant of production. She uses Granger causality tests and focuses on 12 energy-intensive manufacturing industries in the US. She concludes that for 8 of the 12 industries, there is a significant link between natural gas prices and production, confirming the potential importance of the downstream effect. The present article is in line with the literature that addresses the competitive advantage of the US industry, and mainly Arezki et al. (2017). They investigate the response of US manufacturers to changes in production and trade brought about by the decrease in the price of US natural gas. Various measures of manufacturing activity are investigated, using a panel data model of 158 US industries trading with 218 countries and territories. The results suggest that the fall in US gas prices since 2006 has been associated with

a 10 percent increase in exports for the whole US manufacturing sector. They find no impact on imports and claim that the US shale revolution is operating both at the intensive and extensive margins.

To sum up, few quantitative studies have figured out a positive but relatively small impact on the competitiveness of the US manufacturing industry as a whole, except for the effects on employment pointed out by Morse et al. (2012) and on exports by Arezki et al. (2017).

This study considers the manufacturing sector as defined in the North American Industry Classification System (NAICS).<sup>6</sup> It aims to provide a sound assessment of the impact of the production of shale gas on the US manufacturing sector. To do so, it assesses the impact on several macroeconomic variables of the price difference of natural gas between the US and Europe, induced by the production of shale gas using annual data for a group of 80 industries over the period 1997-2013. More specifically, in this article we first build an "energy intensity" variable, from the MECS (Manufacturing Energy Consumption Survey) survey conducted in 2006, which gives a precise indication of the industries that are more likely to take advantage from the drop in gas prices. This variable gives information on natural gas and energy consumption levels close to the date of the positive supply shock on the US gas market. We then test whether a structural break occurred in the relationships between five macroeconomic variables and natural gas prices after the sharp drop in natural gas price from 2006. We find evidence of structural breaks in the interrelationships with natural gas prices only for imports and exports. We finally estimate a dynamic panel data model which allows computing the short-term and long-term elasticities. The results indicate that the decline in natural gas prices in the US relative to the price of natural gas in Europe has led to an increase in industrial activity and investment of nearly 3%, for the whole manufacturing sector. When we account for structural breaks, we find that exports increase by nearly 1% while imports decrease by nearly 1%. As for the sectoral impact, there is a significant disparity. Indeed, the industrial activity in the most intensive sectors reacts to the decline in gas prices by an increase of at least 30%. Moreover, we find that even if some industries are expanding, this does not seem to have a significant effect on the whole manufacturing sector till now. These results should be interpreted with caution given that firms adjust their production processes only gradually. Perhaps the overall effect of this energy boom is still to come and has not yet been realized.

The remainder of the paper is structured as follows. In section 2, we discuss the existing markets

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6. The North American Industry Classification System (NAICS) is the system of classification used by federal statistical agencies to categorize the products and services of business establishments in order to gather, analyze and provide statistical data on business activities in the United States economy, US Census Bureau.

place of natural gas and their implications on gas prices. Section 3 describes the datasets used and discusses the empirical strategy. Section 4 presents the main results. Section 5 concludes.

## 1.2 The natural gas market and the economy

### 1.2.1 Specificity of the natural gas market

The international natural gas markets are not integrated like international oil markets (Li et al., 2014). They are segmented into three different geographical areas: North America, Europe and Asia. The prices set in natural gas markets are governed by different mechanisms. However, they mostly have similarities related to the intrinsic characteristics of natural gas which led to entry barriers. These barriers are related to high transport costs (by pipeline or methane tanker) and high transformation costs (liquefaction, regasification) necessary to allow the product to be marketed. Gas transportation generates the largest costs in the gas industry (Maxwell and Zhu, 2011). The specific constraint of this type of energy product stems from its gaseous state and its relatively low density. Indeed, one ton of gas represents the energy equivalent to 0.89 tons of oil, which is about the same order of magnitude. However, a ton of oil occupies a volume of  $0.85m^3$  while a ton of gas occupies a volume of  $1000m^3$ . Thus, the transport of the same amount of energy under standard condition of temperature and pressure is generally 4 to 6 times more expensive (Lochner and Bothe, 2009). Pipelines are the most frequently used method for the transportation of natural gas in world trade (about 80%). In order to be transported by pipeline, gas is compressed and maintained under pressure by compressors installed every 100 km or less, over distances up to 6,000 km. This compression allows the volume of gas to be reduced. Pipelines can be over land (North America and Russia), submarine or underwater (North Sea). The gas may also be transported by ships. To be efficiently transported by ships, natural gas must be transformed into a liquid state at a temperature of  $-160^{\circ}C$ . Once stored as a liquid, its volume is 600 times smaller than in its gaseous state and can then be carried by refrigerated tanks to a regasification plant. These exorbitant transportation costs create significant regional gas price differentials, and provide a competitive advantage to the various economic players in the region which offers the lowest prices. It is the case of North America.



### 1.2.2 Trends in US gas market

In the early 2000s, the US oil and gas industries were concerned about the depletion of conventional natural gas reserves. Most experts believed that North America would become a net importer of LNG. The US Energy Information Administration (EIA), in its Annual Energy Outlook 1999, anticipated an increase of 12.9% to 15.5% of net imports of natural gas between 1997 and 2020, knowing that consumption increased faster than production. To face up to this situation, five new LNG import terminals were built in the second half of 2000s and other existing installations were brought back into service, at increased capacity. However, against all economic forecasts, these facilities will not be of much use since shale gas is far more promising than expected. Starting from 2006, the gas industry realized that shale gas is an important and economically exploitable resource that could complement the depletion of conventional gas wells. In 2005, the EIA reported a 6% increase in proven natural gas reserves, the highest rise since 1970. Driven by high gas prices, over 32,000 exploration and development wells were drilled annually between 2006 and 2008. In 2010, proven reserves of natural gas and oil reached the highest levels recorded by EIA since 1977.<sup>7</sup> The United States became the largest producer of natural gas and oil ahead of Russia. This increase has been possible thanks to technological advances that have allowed exploitation of shale gas, which had not been available neither technically or economically before. In 2000, shale gas represented 1% of the US natural gas supply. The gas obtained from shale currently represents 40% of US gas production, and is experiencing constant growth. According to EIA, shale gas will account for more than 50% of US gas production by 2035. The Annual Energy Outlook 2016 (EIA, 2016) estimates that the United States will become an overall net exporter of natural gas by 2017, when production will exceed domestic consumption. The large availability of domestic natural gas has led the US gas industry to change its objectives and strategies. One of them was the reorientation in the construction of LNG import terminals to become export terminals in the early 2010. More recently (January 2015), there were 48 applications for authorization to build liquefaction facilities to export gas in a liquefied form.

Figure 1.1 shows the increase in total US shale gas production from 2007 onward, as well as the change in the US natural gas price. The increase in shale extraction began in the late 2000s, accelerated in 2010, and amounted to more than 10000 billion cubic feet by late 2013. This strong increase in shale gas production has been stimulated by technological advances in horizontal drilling

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7. Proven reserves of crude oil increased by 13 percent (2.9 billion barrels) and proven reserves of natural gas rose by 12 percent (33.8 trillion cubic feet). Oil reserves at the end of 2010 were 25.2 billion barrels and natural gas reserves at the end of 2010 were 317.6 trillion cubic feet— the first time they reached a level over 300 trillion cubic feet.

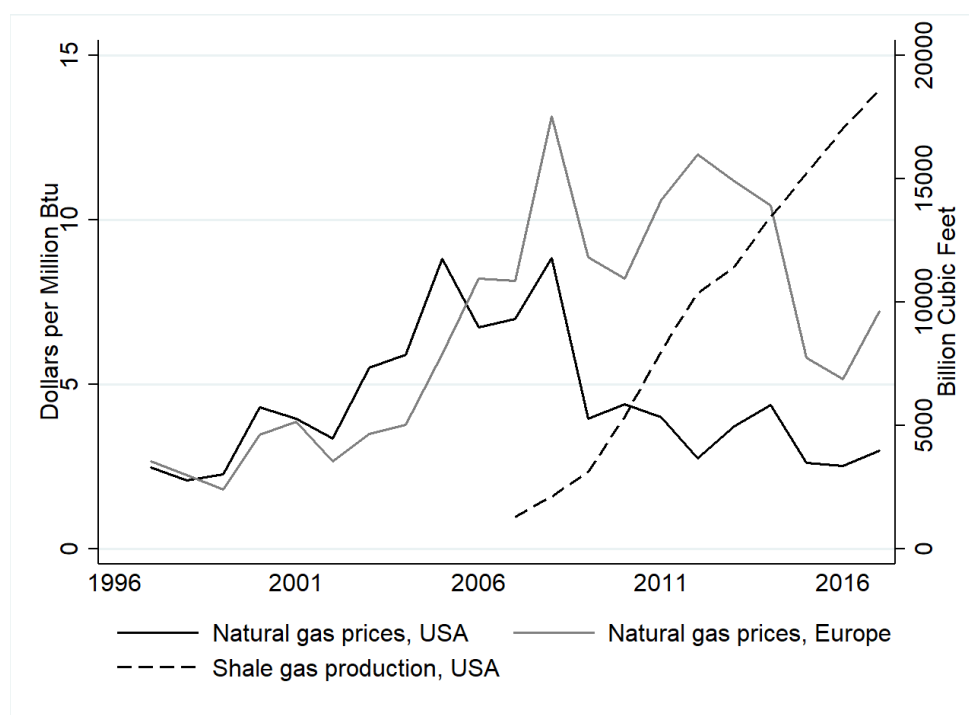


Figure 1.1: The evolution of natural gas prices and shale gas production.  
Source: U.S. energy information administration (EIA)

and hydraulic fracturing. Despite the fact that horizontal drilling and hydraulic fracturing have been used for half a century, they have only become economically viable in large-scale gas extraction in recent years. As a result of this sustained growth in extraction, natural gas prices in the United States have fallen significantly, while not affecting European gas prices due to the regionalized nature of gas markets. This evolution has allowed the United States to become more competitive vis-à-vis Europe, where the gas price is still largely indexed on oil prices, and is three to four times as high as in the US. In 2012, the price of natural gas in Europe was on average 11.40 per MBtu, whereas it was only 2.75 per MBtu in the USA (11.10 and 3.45 respectively in August 2013). The price of imported gas in Europe was thus four times as high as US prices (compared to 2.7 times as high for 2009-2013). These trends have led to prices for European industry which are at least three times as high as prices for US industry. This difference has widened in the last two years, weakening the position of European industry with respect to the US. The picture is particularly problematic for energy-intensive industries facing international competition, such as chemicals, fertilizers and steel, etc.

In the following, we assume the price discrepancy between the US and Europe's natural gas prices allow capturing the effect of the US shale gas revolution. However, one may question whether

variations in gas price difference are entirely due to the shale gas production. The answer is obviously negative and shale gas production cannot explain 100% of the change in the gas price ratio. Indeed, there are differences in the structure of gas markets in Europe and the US which prevent from getting the same gas price at each moment (Hulshof et al., 2016). However, the formation of gas prices on both markets reflects a common pattern: both are indexed to international crude oil prices.<sup>8</sup> We expect from price indexation theory that natural gas prices to be very similar in the US and Europe. Moreover, several studies have found long-run cointegration relationship between gas and oil prices (Asche et al., 2006; Regnard and Zakoian, 2011; Erdős, 2012; Villar and Joutz, 2006). However, since the US shale gas boom, US natural gas prices appear to have decoupled from those of international oil prices and inevitably from European gas prices. Indeed, since 2006, the US gas market become independent from that of European gas market. This is mostly due to the sharp increase in the US gas production induced by the shale gas boom occurred in the mid 2006 (Aruga, 2016).

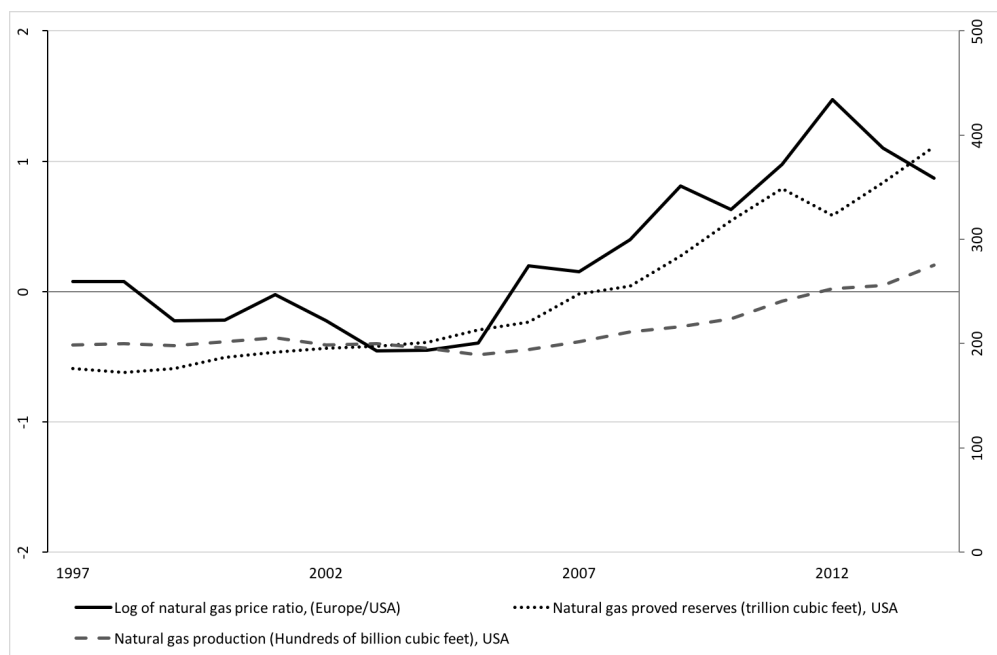


Figure 1.2: Natural gas proved reserve and production impacting natural gas price ratio. Source: U.S. energy information administration (EIA)

Figure 1.2 illustrates the natural log of the natural gas price ratio of Europe over US with the

8. As they are two potentially substitutable energy sources, relative gas and oil prices should reflect differences in their intrinsic calorific content in addition to production and transportation costs. The prices of these commodities must not deviate, or at least not persistently, from their fundamentals which leads to the hypothesis of oil price indexation.

total US proved reserve and production of natural gas. We observe that production and reserves are stable for the period before 2005. The price ratio fluctuates slightly, but remains stable. From 2006 onwards, we notice a significant increase in production, reserves, and in the price ratio. As discussed previously, the shale gas boom in the USA corresponds to this date. This is why we assume that the largest part of the change in the price ratio is due to the emergence of shale gas. To provide some additional evidence, we compute correlations between proved reserves, production and price ratio for the 2006-2013 period. The results are quite significant, since we get a correlation of 0.93 between log of price ratio and shale gas production, and a correlation of 0.95 between log of price ratio and natural gas proved reserve. This leads us to be quite confident about the quality of our proxy.

Finally, we recognize that using the shale gas production variable would be preferable. Unfortunately, this variable is only available from 2007 onwards, which greatly reduces the time period for the analysis. Another proxy could be constructed to use a counterfactual natural gas price.

### 1.2.3 The Rebirth of the US manufacturing sector

The unexpected expansion of the domestic energy supply gives an important economic advantage to US industry, which is leading some economists to talk about the US Manufacturing Renaissance (Wang et al., 2014; Bazilian et al., 2014). Indeed, industrial sector is one of the largest consumers of natural gas: it includes manufacturing, construction, agriculture and mining activities. It consumed 8.3 quadrillion ( $10^{15}$ ) Btu of natural gas in 2011, about one third of total US consumption.<sup>9</sup> For instance, the decline in natural gas prices has directly impacted US industry by lowering the costs of electricity production (Wang et al., 2014; Bazilian et al., 2014). During the last two decades, the use of natural gas in electricity generation has significantly increased from 11% in 1990 to 28% in 2012, mainly due to its substitution for coal. It is also a key component used in plastics, polymers, petrochemicals, steel, cement, and fertilizer production. Employment in the oil and gas industry increased by 50,000 jobs in 2012, although it was a small share of the 2.2 million of new jobs created if direct and indirect effects are taken into account (Wosepka et al., 2012). In early 2013, the Boston Consulting Group (BCG) predicted that within five years, the United States would experience a rebirth of the manufacturing sector as companies relocated their manufacturing operations in USA. The report concluded that the benefits of production cost of goods manufactured abroad have dramatically fallen over the last decade. In 2003, manufacturing costs were 18% lower

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9. One British Thermal Unit (Btu) is the heat that will raise the temperature of one pound of water by one degree Fahrenheit

in China than in the US. In 2011, the difference was only of 7%. Natixis, a French corporate and investment bank, has confirmed that the competitive advantages accruing to US industrial manufacturers through lower gas prices are equivalent to a 17% reduction in wage levels compared to firms belonging to the Euro-zone. Players in the manufacturing industry have congratulated themselves for the gas supply surplus, as it reduces their production costs, thus improving their competitiveness. Cheaper energy also has the potential to create significant employment growth in both primary industries and secondary industries. Other actors see the development of natural gas as an opportunity to use less coal in electricity production and reduce dependence on oil through the liquefaction of gas in the transport sector. Gas producers, meanwhile, saw a great opportunity to benefit by exporting natural gas as LNG.

## **1.3 Data and Empirical Specification**

### **1.3.1 Economic intuition and variable of interest**

In order to capture the effect of the exploitation of unconventional gas on various US economic variables, natural gas prices are used here, and more specifically the difference or the ratio of natural gas prices in the US and Europe. The use of gas prices to estimate the effect of shale gas is justified by the positive supply shock which occurred in 2006 in the US gas market due to the massive exploitation of shale gas (Wakamatsu and Aruga, 2013; Aruga, 2016; Caporin and Fontini, 2017). Therefore, US gas prices have moved downwards since 2006. The construction of the variable measuring natural gas prices of the United States compared to the European prices will capture the comparative advantage conferred to US manufacturing. The German border price of natural gas in Europe is used as a proxy for average world prices. This choice was made for two main reasons. First, knowing that Europe and Asia are the major trade competitors of US manufacturing industries, and since a natural gas price gap between the US and Asia is larger than between US and Europe, only the European price is considered, in order to compute the lower bound of the comparative advantage provided to the US industries. Second, Russia and Norway are the two main suppliers of natural gas imported by Europe. They represent respectively 40% and 35% of imports in 2015 (BP Statistical Review 2015). They have a similar indexation, with prices pegged to over 80% on oil fuel products.<sup>10</sup> Consequently, gas purchased from these countries displays similar price levels. Indeed, given the fact that much of the Europe's current supply of gas

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10. According to the Energy Sector Inquiry from the European Commission.

comes from these two countries, it is natural to use Germany's eastern border price. The interest here using the spot price of National Balancing Point (UK NBP) would be limited due to the low representation and use of this gas in continental Europe especially as the UK became a net gas importer since 2005. In addition, by using co-integration analysis of import prices, Asche et al. (2002) found that the Belgium, German and French markets are integrated.

Multiplying the gas price ratio by the energy intensity of each sector allows a new proxy to be constructed, which is more relevant. It distinguishes the advantage of the various sectors according to their energy intensities. Indeed, the new proxy provides a two-fold benefit. The first one is to obtain a measure of sectoral comparative advantages. The second advantage is econometric, as the new proxy creates more variability in the data, which improves the efficiency of the estimators used.

### 1.3.2 Data description

This study aims to identify the response of the US manufacturing sector to the massive development of shale gas. The responses will vary with energy intensity of each sector. To conduct the empirical study that takes advantage of variations in energy intensities by industry, a variable needs to be used that measures this intensity. There are at least four measures of energy consumption allowing computation of the energy intensity for each manufacturing sector; among them the Manufacturing Energy Consumption Survey (MECS) conducted every four years by the US Administration for Energy Information (EIA). Annual Survey of Manufactures (ASM), Bureau of Economic Analysis (BEA) using its KLEM (Capital, Labor, Energy, Materials) dataset and BEA's Input/Output data. The last MECS survey was conducted in 2010 with preliminary results published in March 2012. MECS is a national sample survey that collects information on the stock of US manufacturing establishments, their energy-related building characteristics, and their energy consumption and expenditures. The MECS 2006 sample size of approximately 15,500 plants was drawn from a nationally representative sample frame representing 97%-98% of the manufacturing payroll. The MECS tracks both the energy consumed as fuel (e. g. for heating and lighting) and the energy consumed as a raw material (e. g. naphtha used in ethylene production). Based only on energy consumption as fuel, MECS provides several measures of energy intensity for different sectors. Among them, total fuel consumption in thousands of British thermal units (Btu) per dollar of value added and shipments. These two measures exclude the energy used as feedstock. However, a firm will take advantage of lower energy prices whether hydrocarbons are used as fuel or as

feedstock. It is therefore important to have measures of energy intensities that reflect energy use as fuel or feedstock. Thus, similar measures of energy intensity are calculated, relating to the total energy consumption and total consumption of natural gas in two stages. The first stage aims to reconstruct measures of added value and shipments for each industry covered by the MECS, from the intensity and level data based on consumption as fuel. The second stage consists on dividing the total energy consumption and the total consumption of natural gas (Btu), including fuel and feedstock, by the added value and the shipments constructed in the first step. This provides four measures of energy intensity by sector: a measure of energy intensity of natural gas and of total energy per dollar of value added and per dollar of shipments. Having two measures of calculation (natural gas and total energy) allows taking into account that energy intensive industries (using oil, gas and coal) can substitute other energy sources to natural gas. The four measures are presented in Table 1.6 and 1.7 in the Appendix.

The rest of the study focuses on the measures in thousands of Btu of total energy and natural gas consumption per dollar of added value and per dollar of shipment, from the survey MECS 2006. This choice is justified by the coincidence of the realization of the survey with the boom in the production of shale gas in the US. Accordingly, these measures provide a better indication about which sectors should benefit more from lower gas prices, since they provide information on the levels of gas and the total energy consumption closer to the date of the positive supply shock in the US gas market.

Matching between measures of energy intensity and different economic variables for each industry was achieved on the basis of the North American Industry Classification System (NAICS). The industrial sector in MECS 2006 database, however, may not necessarily correspond exactly to each economic variable. For each organization that produces or participates in the production of these economic variables, they can cover a different set of manufacturing industries and operate the NAICS in a slightly different way. These variables are derived from different sources (see Table 1.8 in the Appendix).<sup>11</sup> Finally, 79 matches for the total energy intensity and 78 for natural gas intensity between the 2006 MECS database and other agencies were made, providing economic variables for each sector.

Five economic variables for each industrial sector are taken into account: industrial production, employment, capital expenditure, exports and imports. Variables are indicated for the period 1997-2013, except for capital expenditures that are only available until 2011, and employment until 2012.

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11. Table 1.8 gives sources and units and shows the number of sectors that are matched with the MECS 2006 database.

All these variables are in volume terms (exports, imports, industrial production) and transformed into logarithms, in order to interpret the results in terms of elasticity. The database also includes natural gas spot prices, using the Henry Hub prices in the United States, and eastern German border price in Europe (both taken from the International Monetary Fund). A balanced panel of 79 industrial sectors is obtained by identification of NAICS codes ranging from 3 to 6 digits, for the period 1997-2013. The number of observations varies with economic variables since they are not all available during the whole period. However, the total number of observations is more than 1000 for all economic variables, allowing us to obtain results from the asymptotic properties of estimators that are used.

### 1.3.3 Methodology

#### Econometric modeling and estimation method

The econometric model to estimate is the following;

$$\ln(Z_{i,t}) = \beta_0 + \gamma \ln(Z_{i,t-1}) + \beta_1 \left[ \ln\left(\frac{NG_t^{USA}}{NG_t^{EUR}}\right) * I_{i,2006} \right] + \beta_2 \left[ \ln\left(\frac{NG_{t-1}^{USA}}{NG_{t-1}^{EUR}}\right) * I_{i,2006} \right] + \alpha_i + \nu_t + \epsilon_{i,t} \quad (1.1)$$

where the variable  $Z$  denotes alternatively industrial production, exports, imports, employment and capital expenditure.  $\left(\frac{NG_t^{USA}}{NG_t^{EUR}}\right)$  is the natural gas price ratio of the US and Europe at time  $t$ , and  $I_{i,2006}$  is the intensity of sector  $i$  in 2006.

It is a linear dynamic panel-data model including one lag of the dependent variable as covariates.<sup>12</sup> Such modeling allows taking into account the gradual adjustments of the dependent variable. Furthermore, it distinguishes between the short term effect and long term effect. For example, the level of industrial production during  $t$  will depend on industrial production during  $t - 1$ , on the ratio of gas prices in  $t$  and  $t - 1$ , on some observable or not observable variables that are fixed in time and captured by individual fixed effects ( $\alpha_i$ ), and finally on macroeconomic shocks (impact on GDP, exchange rates, etc.) caught by time fixed effects ( $\nu_t$ ). The individual fixed effects allow the impact of specific unobservable and observable variables of each sector and constant over time

12. We check for an AR( $p$ ) with  $p > 0$  for all variables and we obtained  $p$  equal to 2 at most. However, in view of parsimony and because the long-run effect (which is our interest) is still the same whatever the model (AR(1) or AR(2), the sum of the coefficients of the AR (2) is equal to the coefficient of the AR (1)). We choose an AR(1) model for all variables. Moreover, for models that have a serial correlation in the first differenced errors of order 2 or more, implementing an AR(2) implies that we will have two endogenous regressors and not only one with the same amount of instrumental variables. So, the AR(2) will better describe the dynamics but with a loss in the quality of estimates (efficiency).



to be captured. The combination of individual fixed effects with time fixed effects avoids any endogeneity problem related to omitted variables. Estimation of this model by the usual estimators of panel data (OLS, between) is biased due to the presence of the lagged dependent variable among the regressors. OLS and between estimators are also biased because of the correlation between the individual effects and some explanatory variables in the model (Imbens and Wooldridge, 2009). An alternative solution is to use the within estimator that can eliminate the fixed effects. This estimator is effective in the linear range of models that do not incorporate the dynamic dimension. However, in the case of a dynamic panel as used here, the within estimator is ineffective and biased. The simple illustration of the bias of the within estimator in dynamic panel is given in the following example. Consider the following simple dynamic model:

$$y_{i,t-1} = \alpha y_{i,t-1} + \beta x_{i,t} + \eta_i + \varepsilon_{i,t} \quad (1.2)$$

Applying the within estimator model eliminates the fixed effects and avoids the problem of endogeneity due to the correlation between individual fixed effects and the explanatory variable  $x_i$ . Then we get:

$$y_{i,t} - y_{i,..} = \alpha (y_{i,t-1} - y_{i,..-1}) + \beta (x_{i,t} - x_{i,..}) + (\eta_i - \eta_i) + (\varepsilon_{i,t} - \varepsilon_{i,..}) \quad (1.3)$$

with

$$y_{i,..} = \frac{1}{T} \sum_{t=1}^T y_{i,t} \quad x_{i,..} = \frac{1}{T} \sum_{t=1}^T x_{i,t} \quad \varepsilon_{i,..} = \frac{1}{T} \sum_{t=1}^T \varepsilon_{i,t} \quad (i =, \dots, n \quad t = 1, \dots, T) \quad (1.4)$$

In this dynamic panel, another endogeneity problem appears when applying the within estimator. The error term  $\varepsilon_i$  contains the error term  $\varepsilon_{i,t-1}$ , then  $E(y_{i,t-1}, \varepsilon_{i,..}) \neq 0$ . We are again faced with the violation of the assumption of exogeneity of the explanatory variables. This violation implies that the within estimator is biased in the framework of a dynamic panel model with a finite time dimension. The bias introduced by the within estimator is known as Nickell bias (Nickell, 1981). The within estimations are provided in the Appendix (see Table 1.13), which highlights the existence of the Nickell bias. This endogeneity problem is tackled by using the Arellano-Bond estimator (Arellano and Bond, 1991). The first stage of Arellano-Bond takes the first difference of regression equation to eliminate the individual fixed effect. It also has the advantage of avoiding any problems related to non-stationary time series in our study, despite the fact that theoretically the time dimension of 15 points is not long enough to deal with the problems of non-stationary

variables (Mignon and Hurlin, 2005). The second stage of the Arellano-Bond estimator uses deeper lags of dependent variables as instruments for differenced lags of the dependent variable (which are endogenous). In order to choose the delay of the dependent variable to use as an instrument, we must first know the order of autocorrelation of the errors term. Then, if we have an autocorrelation of order 1 of the error term in first difference, it implies that we should instrument from lag 2 of the dependent variable. Otherwise, the instrumentation starts at higher lags ( $y_{i,t-3}$  or  $y_{i,t-4}$  depending on the order of autocorrelation of first-differenced errors).

The Arellano Bond estimator is criticized for weak instruments induced by the use of instruments in the level for variables in first difference. This is valid when variables are close to a random walk, but our variables are not. The validity of the instruments can usually be tested through a Sargan test, assuming homoscedasticity disturbances. However, in the estimates here, the residuals' variance-covariance matrix was corrected to account for heteroscedasticity, and once applying the correction, Sargan test statistic cannot be computed. Finally, it cannot be used to test the validity of the instruments employed here. To overcome this limit, we rely on the Hansen J test using `xtabond2` stata command.<sup>13</sup> Finally, we restrict the number of lags of the dependant variable used as instruments between 1 to 3 according to the estimated model. We constraint the number of lags of the dependant variable to be used as instrument in order to avoid the problem of weak instruments which can produce biased IV estimators. In this context, we obtain a various number of instruments depending on the order of autocorrelation of the first-differenced errors of each model (some models have a first-differenced errors serrially correlated at order 2). The total number of instruments is given in the results tables.

Following the positive supply shock on the US gas market, it may be suspected that the relationship between some variables and gas prices undergoes a structural change, meaning that the nature of the link between the channel of natural gas prices and the rest of the variables has changed since 2006. In order to control for structural breaks, Chow-type tests are performed to assess the evidence of breaks in the estimated functions. The results are given in the results tables in the Appendix (Table 1.11 and Table 1.12).

The database accounts for 79 industrial sectors. The estimation of the different parameters of the various models gives two parameters –  $\beta_1$  and  $\beta_2$  – that are the same for all sectors for each dependant variable. Using  $\beta_1$  (or  $\beta_2$  when  $\beta_1$  is not significantly different from zero), the short-term elasticity of each of the dependent variables for each sector is computed, with respect to the ratio

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13. Hansen J's statistics are presented in the results tables.

of gas prices.

$$\ln(IP_{i,t}) = \beta_0 + \gamma \ln(IP_{i,t-1}) + \beta_1 \left[ \ln\left(\frac{NG_t^{USA}}{NG_t^{EUR}}\right) * I_{i,2006} \right] + \beta_2 \left[ \ln\left(\frac{NG_{t-1}^{USA}}{NG_{t-1}^{EUR}}\right) * I_{i,2006} \right] + \alpha_i + \nu_t + \epsilon_{i,t} \quad (1.5)$$

In the equation (2.5), the short-run elasticity of industrial production (IP) with respect to the gas price ratio is computed, which gives us  $\beta_1 * I_{i,2006}$ . Finally, as many different short run elasticities as sectors are obtained, thanks to the energy intensity measure. The computation of long-run elasticities of the different dependent variables with respect to gas price ratio assumes that the variables are stationary. As an example, the long-run elasticity of industrial production (IP) with respect to the gas price ratio is  $((\beta_1 + \beta_2)/1 - \gamma) * I_{i,2006}$ .<sup>14</sup> Finally, the advantage of taking into account the energy intensities for different sectors becomes clear, because the elasticities differ with intensity.

The computation of the overall elasticity of the manufacturing sector is done by weighting the different sectoral elasticities by the weight of each manufacturing sector in the economy (measured by the ratio of its value added to the total value added of all sectors):

$$Overall\_Elasticity = \sum_{i=1}^{79} Long\_term\_Elasticity_i * Sector\_share_i \quad (1.6)$$

These elasticities are available in the Appendix Table 1.14 and Table 1.15.

## 1.4 Empirical results

We first discuss the results section with a detailed analysis of the impact of natural gas price ratio on capital expenditure variable. Once the operating procedure is detailed, readers can refer to the Appendix regarding results of different explanatory variables. Then, we investigate the long-term elasticities of the different sectors and their overall impact on the manufacturing sector.

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14. The delta method estimates the standard errors of transformations of a random variable using a first-order Taylor approximation. Regression coefficients are random variables, we can use the delta method to approximate the standard errors of their transformations.

### 1.4.1 GMM results

Theoretically, we expect the coefficients to be negative and significant in the capital expenditure, industrial output, employment and export equations as a drop in relative natural gas prices would lead firms to invest more, produce more, hire more and export more. Conversely, the coefficient should be positive and significant in import equation as a drop in natural gas prices would lead U.S. firms to lower prices and discourage imports from foreign manufactures.

Table 1.1 presents the effect of the shale gas boom on capital expenditure across sectors for different measures of intensity. Using natural gas consumption per dollar of value added as the energy intensity, the estimated effect is negative and significant. It suggests that gas intensive sectors of the economy expand differentially as relative natural gas prices drop. The coefficient implies that, in the case of Nitrogenous Fertilizers, which has the highest energy intensity, investment expands by  $300.09 * 0.0037 = 1.11\%$  for every dollar that the relative price gap decrease in the short term. In the long term, investment expands by  $((0.0037 + 0)/(1 - 0.316)) * 300.09 = 1.66\%$  for every dollar that the relative price gap decrease. With these estimates, it is possible to calculate the impact of a specified change in the relative price of natural gas using long-term elasticity. Between 2006 and 2013, relative natural gas prices fell by about 65%. Given such a wide variation, the exact percentage change in capital expenditure variable, for Nitrogenous Fertilizers, is  $1.66 * 65 = 107.9\%$ . It is associated with approximately a two-fold increase in capital expenditure. For the remaining three intensity measures, the findings are qualitatively the same. Therefore, a weighted average of the effect is computed from all industries, which is based on each industry's share of total value added or total shipments using the energy intensity measure. Overall, in the US manufacturing sector, an increase in capital expenditure directly resulting from the shale gas boom over the period 2006-2013 is estimated as ranging from 1.65% to 3.26% depending on the various intensity measures. Indeed, having two measures of calculation (natural gas and total energy) allows taking into account that energy intensive industries (using oil, gas and coal) can substitute other energy sources to natural gas.

In addition, all the diagnostic statistics are satisfactory in this table. Specifically, the Hansen test does not reject the over identification restrictions; the absence of first-order serial correlation is rejected, while the absence of second-order serial correlation is not rejected.<sup>15</sup> Moreover, the lagged dependent variable has positive and statistically significant coefficients in all the equations. These coefficients are quite small and statistically different from unity, suggesting a weak persistence. Fi-

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15. These results are not tabled in order to save space. Full results are available from the author upon request.

nally, De Hoyos and Sarafidis (2006) highlight when a cross-sectional dependence of the disturbance occurs, any estimate technique relying on the instrumental variable and the generalized method of moments (GMM) such as Arellano and Bond (1991) are inconsistent. We run various standard tests for cross-sectional dependence proposed by Pesaran (2004) and Frees (1995), that do not reject the absence of cross-sectional independence. Therefore, we conclude from the diagnostic statistics that the system GMM is an appropriate estimator for our analysis.

The results in Table 1.1 are fairly typical of the estimates for all activity measures of the four MECS-based energy intensity measures. The estimated responses for the four activity measures (industrial production, employment, exports and imports) are presented in the Appendix. The same method is used for each variable. As expected, the industrial production, employment and export equations, along with declining relative natural gas prices, lead firms to produce more, hire more and export more. Conversely, the coefficient is positive and significant in the import equation, as a decline in natural gas prices causes U.S. companies to lower their prices and discourages imports of foreign manufactured goods.

Table 1.1: Estimation results for capital expenditure

Estimation method	GMM-IV (Arellano-Bond)			
Energy Intensity measure	Natural gas per \$ of Value added	Natural gas per \$ of Shipments	Total energy per \$ of Value added	Total energy per \$ of Shipments
$Capital.E_{i,t-1}$	0.316** (2.19)	0.322** (2.24)	0.303** (2.19)	0.309** (2.21)
$(NG^{USA}/NG^{EUR})_t$	-0.0037*** (-7.02)	-0.0136*** (-5.52)	-0.0024** (-2.23)	-0.0059* (-1.80)
$(NG^{USA}/NG^{EUR})_{t-1}$	0.0014* (1.77)	0.007 (1.60)	0.00056 (0.91)	0.0024 (1.50)
Time fixed effects	Yes	Yes	Yes	Yes
Sectors	78		79	
Observations	1014		1027	
Time Period	1999-2011		1999-2011	
Total elasticity	-0,019	-0,030	-0,042	-0,050
Growth_rate <sub>2006-2013</sub>	1.26	1,95	2,76	3,26
Number of instruments	38			
Hansen J statistic	21.89	22.13	20.83	20.60
	<i>No Reject H<sub>0</sub></i>			
Cross sectional independence test: Pesaran	(-1.320)	(-1.351)	(-1.433)	(-1.437)
Cross sectional independence test: Frees	(0.961)	(0.978)	(1.066)	(1.100)

Note: t-stat are in (); \*, \*\* and \*\*\* denote the significance levels at 10%, 5%, 1%.

## 1.4.2 Long term elasticities results

### Gas intensive measure

This section focuses on the presentation and interpretation of the long-term elasticities. Table 1.14 Table 1.15 in the Appendix present the long run elasticities for all variables of US manufacturing sectors, with respect to the natural gas price ratio of the US and Europe. They are statistically significant at the 5% level and consistent with the expected signs. Indeed, industrial production, employment, capital spending and exports have all increased with the decline in the relative prices of natural gas, while imports have declined. As a result of our estimation strategy, the response to shale gas operations varies greatly between sectors according to their energy intensity. The most energy-intensive industries have the highest short term and long term elasticities in absolute terms for all the variables. The decline in the relative price of natural gas over the period of 2006-2013 was about 65%. It was associated with approximately a two-fold and a 0.03% increase in capital spending; a three-fold and 0.06% rise in industrial production; a 59% and 0.015% increase in exports; and a rise of 13% and 0.003% of employment for the most gas-intensive<sup>16</sup> and the least gas-intensive<sup>17</sup> industries, respectively. The imports decreased by 61% and 0.015% for for the most gas-intensive and the least gas-intensive industries, respectively.

Table 1.2 gives the long term elasticities of the top 20 gas-intensive industries for all the variables.<sup>18</sup> The first remark that can be made is about the high elasticity of the nitrogenous fertilizers, due to outsized energy intensity of their production, which itself is linked to the outsize use of methane from natural gas to produce amonia. In order to check that the results here are not mainly driven by this industry, the response of the variables for a sample that does not include this industry is computed. The results still hold without this industry, so we can say that they are not driven by one potential outlier.<sup>19</sup> The second remark concerns the asymmetric response of the variables to the price decline. In fact, these variables split in two groups: in one group, capital expenditure and industrial production react relatively more to the price decline than in the second group, which consists of exports, imports and employment. Finally, the shale gas boom has a larger effect on the domestic market than on the international market. If we take a closer look at the results, we see that average long term elasticities for the top 20 gas-intensive for industrial production (-0.36) and capital expenditure (-0.17) are higher than for exports (-0.0931) and imports (0.0972). In addition,

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16. Nitrogenous Fertilizers

17. Tabacco

18. See Table 1.14 Table 1.15 in Appendix for more details.

19. Results are available upon request.

elasticities of capital expenditure (-0.17) are significantly higher than those of employment (-0.018). This difference may be related to the domination of industries which are capital intensive. The manufacturing sector is composed of heavy industries like chemicals and plastics, steel production, oil refining and many others, requiring large investment for market entry. This could explain the weak impact of lower gas prices on employment.

Table 1.2: Long-term elasticity for the 20 most gas-intensive sectors (total gas consumption)

Industries	IP	CE	Emp	Exp	Imp
Nitrogenous Fertilizers	-3.5479	-1.6683	-0.1989	-0.9046	0.9440
Alkalies and Chlorine	-0.5117	-0.2406	Nd	-0.1305	0.1361
Carbon Black	-0.3743	-0.1760	Nd	-0.0954	0.0996
Flat Glass	-0.3477	-0.1635	-0.0194	-0.0886	0.0925
Glass Containers	-0.2244	-0.1055	-0.0125	-0.0572	0.0597
Ethyl Alcohol	-0.2114	-0.0994	-0.0118	-0.0539	0.0562
Gypsum	-0.1953	-0.0918	-0.0109	-0.0498	0.0519
Other Basic Organic Chemicals	-0.1858	-0.0874	-0.0104	-0.0473	0.0494
Industrial Gases	-0.1819	-0.0855	-0.0102	-0.0464	0.0484
Plastics Materials and Resins	-0.1811	-0.0851	-0.0101	-0.0461	0.0482
Phosphatic Fertilizers	-0.1808	-0.0850	-0.0101	-0.0461	0.0481
Secondary Smelting and Alloying of Aluminum	-0.1631	-0.0767	-0.0091	-0.0416	0.0434
Wet Corn Milling	-0.1497	-0.0704	-0.0083	-0.0381	0.0398
Iron and Steel Mills	-0.1395	-0.0656	Nd	-0.0355	0.0371
Paperboard Mills	-0.1307	-0.0614	-0.0073	-0.0333	0.0347
Synthetic Rubber	-0.1243	-0.0584	-0.0069	-0.0317	0.0330
Alumina and Aluminum	-0.1228	-0.0577	-0.0068	-0.0313	0.0326
Noncellulosic Organic Fibers	-0.1188	-0.0558	Nd	-0.0302	0.0316
Aluminum Sheet, Plate and Foils	-0.1144	-0.0537	-0.0064	-0.0291	0.0304
Mineral Wool	-0.1030	-0.0484	-0.0057	-0.0262	0.0274
Glass Products from Purchased Glass			-0.0051		
Pulp Mills			-0.0048		
Nonmetallic Mineral Products			-0.0048		
Primary Metals			-0.0047		
$((\beta_1 + \beta_2)/1 - \gamma)$	-0.012**	-0.006***	-0.001***	-0.003***	0.003**
	(-2.58)	(-5.163)	(-3.333)	(-3.928)	(2.064)
Average elasticity of the twenty most gas-intensive sectors	<b>-0.3654</b>	<b>-0.1718</b>	<b>-0.0182</b>	<b>-0.0931</b>	<b>0.0972</b>
Average elasticity of the twenty less gas-intensive sectors	<b>-0.0060</b>	<b>-0.0028</b>	<b>-0.0003</b>	<b>-0.0015</b>	<b>0.0016</b>

Note:  $((\beta_1 + \beta_2)/1 - \gamma) * I_{i,2006}$  corresponds to the computation of long-run elasticities of each dependent variable with respect to gas price ratio. However, we need to check the significance level of  $((\beta_1 + \beta_2)/1 - \gamma)$  using the delta method that estimates the standard errors of transformations of a random variable using a first-order Taylor approximation.

t-stat are in (); \*, \*\* and \*\*\* denote the significance levels at 10%, 5%, 1%.

Nd: Not-documented means that data were not available for specific industries.

Table 1.3 shows overall long-term elasticities and the impact of shale gas boom over the period 2006-2013, using gas intensive measures. The results appear to be robust to the two different measures of gas consumption, as there is not much variation in the response between the two measures. Despite the fact that the response of energy intensive industries is very large (see Table 1.2), the overall effect is quite modest (see Table 1.3). We obtain an elasticity of -0.057 for industrial production, -0.030 for capital expenditure, -0.010 for exports, -0.003 for employment and 0.017 for imports. This weak global effect of shale exploitation on the manufacturing sector as a whole is explained by the small share of the top 20 gas intensive industries in the total value added of the manufacturing sector.<sup>20</sup>

The total impact of a decline in the relative price of natural gas over the period of 2006-2013 is computed, taking into account the share of the value added and shipment of each sector in the economy. Results show an increase of 3.2% for IP, 1.60% for CE, 0.20% for Emp, 0.70% for exports and a decrease of 0.90% for imports over the 2006-2013 period (see Table 1.3). It should be noted, however, that these responses using a gas intensive measure do not take into account a possible substitution from coal and oil to gas that may occur due to the lower gas prices. Finally, these results provide the minimal impact of shale gas operations on US manufacturing sector.

Table 1.3: Long term elasticities and shale gas impact for 2006-2013 period (gas consumption)

Variables	IP		CE		Emp		Exp		Imp	
	NGVA	NGSH	NGVA	NGSH	NGVA	NGSH	NGVA	NGSH	NGVA	NGSH
Overall elasticity	-0.041	-0.057	-0.019	-0.030	-0.002	-0.003	-0.010	-0.011	0.010	0.017
Shale gas impact	2.68%	3.76%	1.26%	1.95%	0.14%	0.25%	0.68%	0.76%	-0.71%	-1.11%

Note : Overall elasticity is computed by weighting the different sectoral elasticities by the weight of each manufacturing sector in the economy. NGVA and NGSH corresponds to gas intensity measures per dollar of value added and per dollar of shipments, respectively.

### Total energy intensity measure

Table 1.4 gives the long term elasticities of the top 20 energy-intensive industries for all the variables which allow the differentiated impact of substitution possibilities among sectors to be taken into account, according to their energy use as energy sources or as feedstock. Despite the fact that elasticities are also robust, consistent, and of the expected signs, the new top 20 energy intensive industries show some differences relative to the top 20 gas intensive industries. First, the use of total energy consumption as a measure changes the rank order in the top 20. Some industries

<sup>20</sup>. Figure 1.3 and Figure 1.4 in Appendix.



which are oil or coal intensive enter into the top 20 because they use a large amount of an energy source other than gas. Second, the value-added share of the top 20 rose from 5% to 13%, due to the fact that these new sectors carry a larger weight in the manufacturing sector. This constitutes a significant increase of 8 percentage points, compared to top 20 intensive-gas sectors. Third, total energy consumption as a measure allows computation of the maximum impact that may result from the exploitation of shale gas, assuming that gas prices remain at low levels. Low gas prices are a signal for industries that are consuming oil and coal as a substitute for natural gas, in the long-term.

Table 1.5 presents the results for overall long term elasticities and percentage of variation over the period 2006-2013. The overall impact is greater for all the variables when we assume that oil and coal consuming industries became exclusively gas consuming industries. This overall effect may be characterized as a maximal effect that may occur if the substitution process is achieved totally by all industries.

### **Overall effect**

In the presence of 79 industrial sectors, a measure of the overall impact on all manufacturing sectors is useful. The aggregate effect is computed as a weighted average of the effects of each sector, based on the share of each sector in total value added of all manufacturing sectors in 2011. The results show that the total effect on the manufacturing sectors as a whole, when the gas intensive measure is used, is relatively low (see Table 1.3). Indeed, over the period 2006-2013, capital expenditure increased by 2%, industrial production increased by 3%, while employment and exports showed an increase below 1%. Imports fell by about 1%. The impact of shale gas is weak on the manufacturing sector as a whole. This weakness is due to the small share represented by the most energy-intensive industries in the total value added of manufacturing sectors. Let us now focus on the comparison between the most and the least 20 energy-intensive industries. The first group of industries accounts for 5% of the total value added of manufacturing sectors, while the second group represents 45%. As the manufacturing sector is dominated by low energy intensive industries, it reacts weakly to the shale gas boom. From these results, it appears that claiming there has been a renaissance of the American manufacturing sector following massive shale gas exploitation would be premature, even with the results obtained with the total energy measures. However, the revival of some of the most gas-intensive industries is an undeniable fact.

Furthermore, on the whole, the estimates are broadly consistent with previous studies. Celasun

Table 1.4: Long-term elasticity for the 20 most energy-intensive sectors (total energy consumption)

Industries	IP	CE	Emp	Exp	Imp
Type of energy	TEVA	TEVA	TEVA	TEVA	TEVA
Nitrogenous Fertilizers	-1.121	-1.081	-0.229	-0.349	0.621
Other Petroleum and Coal Products	-0.575	-0.554	-0.118	Nd	Nd
Carbon Black	-0.514	-0.495	Nd	-0.160	0.285
Lime	-0.435	-0.420	-0.089	-0.135	0.241
Pulp Mills	-0.410	-0.396	-0.084	-0.128	0.227
Plastics Materials and Resins	-0.250	-0.241	-0.051	-0.078	0.138
Paperboard Mills	-0.233	-0.225	-0.048	-0.073	0.129
Alkalies and Chlorine	-0.224	-0.216	Nd	-0.070	0.124
Petroleum Refineries	-0.217	-0.209	-0.044	-0.068	0.120
Petroleum and Coal Products	-0.198	-0.191	-0.040	-0.061	0.110
Cements	-0.190	-0.183	-0.039	-0.059	0.105
Electrometallurgical Ferroalloy Products	-0.169	-0.163	Nd	-0.053	0.094
Wet Corn Milling	-0.158	-0.152	-0.032	-0.049	0.088
Other Basic Organic Chemicals	-0.152	-0.147	-0.031	-0.047	0.084
Other Pressed and Blown Glass and Glassware	-0.148	-0.143	-0.030	-0.046	0.082
Newsprint Mills	-0.148	-0.143	-0.030	-0.046	0.082
Petrochemicals	-0.144	-0.138	-0.029	-0.045	0.080
Flat Glass	-0.141	-0.136	-0.029	-0.044	0.078
Paper Mills. except Newsprint	-0.128	-0.123	-0.026	-0.040	0.071
Iron and Steel Mills	-0.124	-0.119	Nd	-0.039	0.069
Industrial Gases			-0.025	-0.038	0.068
Sugar Manufacturing			-0.023		
Paper			-0.021		
Alumina and Aluminum			-0.019		
$((\beta_1 + \beta_2)/1 - \gamma)$	-0.004***	-0.003**	-0.001***	-0.001**	0.002**
	(-3.03)	(-2.332)	(-3.267)	(-2.54)	(2.200)
Average elasticity of the twenty most energy-intensive sectors	<b>-0.28</b>	<b>-0.27</b>	<b>-0.05</b>	<b>-0.08</b>	<b>0.14</b>
Average elasticity of the twenty less energy-intensive sectors	<b>-0.001</b>	<b>-0.004</b>	<b>-0.0009</b>	<b>-0.0014</b>	<b>0.0024</b>

Note:  $((\beta_1 + \beta_2)/1 - \gamma) * I_{i,2006}$  corresponds to the computation of long-run elasticities of each dependent variable with respect to gas price ratio. However, we need to check the significance level of  $((\beta_1 + \beta_2)/1 - \gamma)$  using the delta method that estimates the standard errors of transformations of a random variable using a first-order Taylor approximation.

t-stat are in (); \*, \*\* and \*\*\* denote the significance levels at 10%, 5%, 1%.

Nd: Not-documented means that data were not available for specific industries.

TABLE 1.5: Long term elasticities and shale gas impact for 2006-2013 period (total energy consumption)

Variables	IP		CE		Emp		Exp		Imp	
	TEVA	TESH	TEVA	TESH	TEVA	TESH	TEVA	TESH	TEVA	TESH
overall elasticity	-0.044	-0.054	-0.042	-0.050	-0.0085	-0.0103	-0.014	-0.035	0.025	NS
Shale gas impact	2.86%	3.52%	2.76%	3.26%	0.56%	0.67%	0.90%	2.30%	-1.65%	NS

Note : Overall elasticity is computed by weighting the different sectoral elasticities by the weight of each manufacturing sector in the economy. TEVA and TESH corresponds to energy intensity measures per dollar of value added and per dollar of shipments, respectively.

NS: Not significant. It indicates that the coefficients resulting from this intensity measure is not significant at the 5% level.

et al. (2014) Points out that a reduction of 50% in the relative prices of natural gas leads to a 1.5% increase in industrial production, while the results of Morse et al. (2012) are consistent with a 3 percent increase in manufacturing output. However, the present study highlights two significant differences with Arezki et al. (2017). It finds that exports increase by 0.75 percent while they found a 10 percent increase. Also they found no impact on imports, while the impact identified is roughly 1 percent. These differences could be a result of not taking into account the potential occurrence of a structural break in their estimation. The present study has checked for a structural break for the five measures of activity. It finds that a structural break occurs for export and import variables (see Table 1.11 and Table 1.12 in the Appendix), meaning that the nature of the relationship between exports, imports, and natural gas prices over the period 2006-2013 may have been different to the period 1997-2005, following the positive supply shock in the US gas market. It can clearly be seen that the nature of the relationship has changed between the two periods, because the estimated parameter is significantly different between the two periods for exports and imports. The break point occurred in 2006, which coincided with the boom of shale gas in the US market.

Now, we discuss our results with regard to the literature that assesses the impacts of shale gas at the regional level, although this is slightly different from our study. Indeed, the empirical literature evaluating the regional outcomes of the shale boom has expanded in recent years. These studies use a variety of methods and focus on given geographical locations to evaluate the impact of the shale gas boom on different socio-economic outcomes. Several studies show a positive effect on total local employment resulting from shale development in the United States. Among them Weber (2014) studies the southern central zone of the United States where Weber (2014, 2012) and Brown (2014) are devoted to the central area of the United States. Specifically, Maniloff et al. (2014) estimate that the shale boom created about 220,000 local jobs in boom areas. However, these impacts, whether on employment or even on income, are limited overall to the oil and gas industry (Feyrer et al., 2017). Positive spillovers can also occur in sectors not directly related to the extractive

activity, but this limits to the construction, transport and leisure sectors (Feyrer et al., 2017).

In the manufacturing sector, spillovers effect at regional level may be negative. Wages in the oil and gas industries are generally higher than those offered by agriculture, manufacturing or services in those regions. This explains the potential negative impact on employment on the traded sector, since workers in these industries are likely to shift from those sectors to the higher paid oil and gas sector. As Cosgrove et al. (2015) and DeLeire et al. (2014) pointed out, the tradable manufacturing sector shrunk due to the boom in shale gas in the Marcellus shales. Alternatively, some studies show that either the shale boom produced a beneficial employment spillover to the traded sector or did not negatively affect it (Weber, 2014; Brown, 2014). There is a high degree of heterogeneity in the conclusions of the various studies on the impacts of shale gas at the regional level. This may be due to the difference in the initial conditions of the different regions in addition to different estimation methods. Berry et al. (2019) emphasizes that regions with less favorable geography tend to benefit more from the development of natural resources than those with more favorable geography, which would reconcile the diverging findings of the literature.

Finally, the results at the micro level support ours, the effect of shale gas is substantial on a few industries (extraction, construction, transport, leisure) but is low or even negative on the manufacturing sector.

## 1.5 Conclusion

This study measures the impact of shale gas on the US manufacturing sector through different economic variables related to this sector. The economic benefit from the exploitation of shale gas is assumed to be captured by the impact of the relative fall in the price of natural gas in the United States compared to the price of gas in Europe. The effect of this decline on industrial production, exports, capital expenditure, employment and imports is measured through calculations of elasticities according to their energy intensities for different industrial sectors. This paper distinguishes between short-run elasticities and those of long-term. The results show that the impact of the positive supply shock of natural gas following the massive exploitation of shale gas on the manufacturing sector as a whole has been relatively low, considering the substitution effect or not. However, even if this impact is very significant for the most energy-intensive manufacturing industries, the latter account only for a small share in the total value added of the manufacturing sector. The revival of some of the most gas-intensive industries is an undeniable fact. Yet, claiming there has

been a renaissance of US manufacturing sector would be premature. As in the case of electric sector where shale gas is gradually replacing coal for electricity generation, financial incentives are needed to encourage the use of large amount of natural gas by the rest of industries that represent 95% of the total value added.<sup>21</sup> In a world where the growth and sustained development matters now more than ever, shale gas may be a key player in the transition path between nowadays energy mix and hopeful futur that would chiefly involve renewable energy sources. On top of the direct effect on climate change, implementing such policy would also increase the overall effect of shale gas exploitation on US manufacturing sector and may lead to the renaissance of the whole manufacturing sector.

Furthermore, by carefully analysing the European gas market, it is observed that this market increasingly depends on imports, especially due to the fact that UK, which is the second-largest producer of natural gas in the EU, became a net importer of crude oil and natural gas as of 2004 and 2005 respectively.<sup>22</sup> Given the increasing dependence of the EU gas market on imports and the surge of domestic gas supplies in the US, the comparative advantage of the US manufacturing sector is likely to continue and at least will remain stable in the coming years. However, this situation could change if the U.S Department of Energy (DOE) lifts the ban on US gas exports to the European market. In this case, US gas prices would increase and EU gas prices would decrease, which would greatly reduce the differential and offset the comparative advantage resulting from shale gas extraction.

The shale gas and oil revolution combined with the possible lifting of the ban has the potential to change the game and revive trade policy issues of a new type that the United States has not had to consider for several decades. If the US exports natural gas, will this nullify the new found energy cost advantage of US manufacturing? Since the US congress fully liberalized exports of all grades of US crude oil, will US energy security be threatened? These are complex questions of major importance that need to be analyzed carefully in further research. However, there is no evidence yet showing that relaxing trade in US energy resources will cancel the domestic economic benefits of the boom or threaten the US energy security.

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21. Coal-fired power plants produced more than half of the total electricity supply in 1990, and natural gas-fired power plants 12%; in 2013, the figures are respectively 29% and 27% (Energy Information Administration, 2014).

22. Source : U.S EIA, Country Analysis Brief : United Kingdom.

## 1.6 Appendix

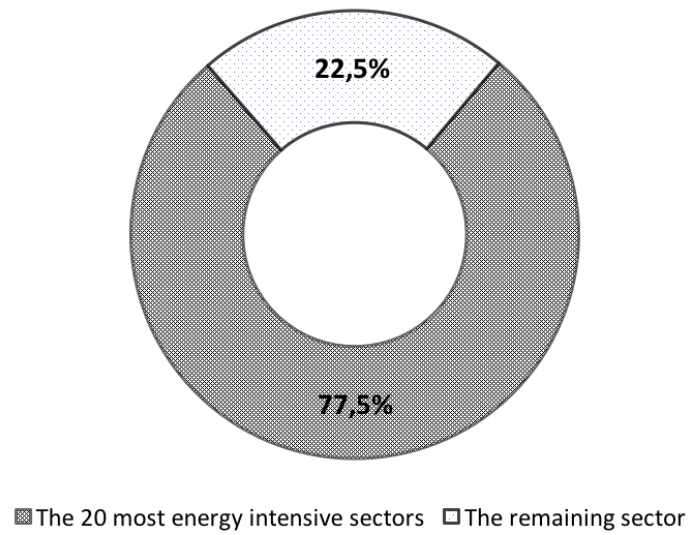


Figure 1.3: Share of energy intensity  
Source: Author calculation

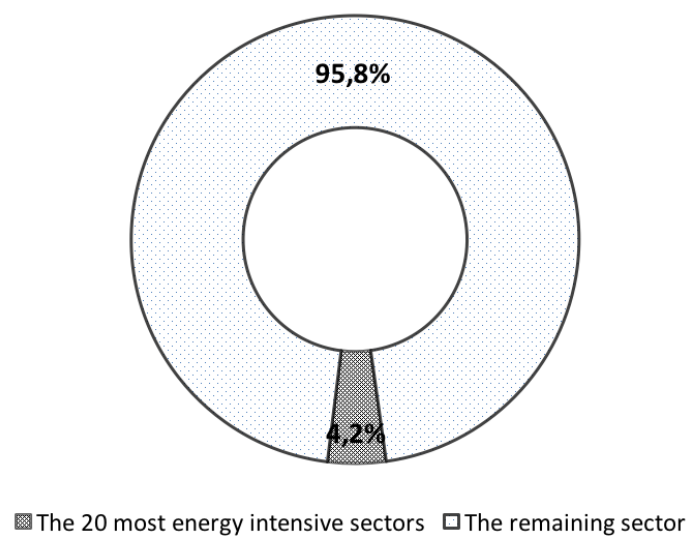


Figure 1.4: Share of value added  
Source: Author calculation

TABLE 1.6: Energy intensity of 2006 (Thousand BTUs per \$ of Value Added and Shipments)

NAICS Code	Industries	Natural	Total	Natural	Total
		gas	energy	gas	energy
		per \$ of Value Added		per \$ of Shipments	
325311	Nitrogenous Fertilizers	300.09	309.31	87.44	90.12
325181	Alkalies and Chlorine	43.28	61.9	22.37	32
325182	Carbon Black	31.66	141.66	12.79	57.23
327211	Flat Glass	29.40	39.02	15.94	21.15
327213	Glass Containers	18.98	24.3	11.01	14.10
325193	Ethyl Alcohol	17.88	24.56	10.26	14.09
32742	Gypsum	16.52	18.7	9.72	11
325199	Other Basic Organic Chemicals	15.72	41.96	5.29	14.14
32512	Industrial Gases	15.39	33.76	8.48	18.60
325211	Plastics Materials and Resins	15.32	68.90	4.67	21.03
325312	Phosphatic Fertilizers	15.3	21.74	3.7	5.25
331314	Secondary Smelting and Alloying of Aluminum	13.8	16.1	2.31	2.7
311221	Wet Corn Milling	12.66	43.6	5.28	18.2
331111	Iron and Steel Mills	11.79	34.18	4.44	12.87
32213	Paperboard Mills	11.05	64.4	5.54	32.3
325212	Synthetic Rubber	10.51	17.8	3.54	6
3313	Alumina and Aluminum	10.39	25.52	2.83	6.97
325222	Noncellulosic Organic Fibers	10.05	21.57	3.9	8.37
331315	Aluminum Sheet, Plate and Foils	9.67	13.6	2.34	3.3
327993	Mineral Wool	8.71	12.7	5.49	8
327215	Glass Products from Purchased Glass	7.84	9.8	4.08	5.1
32211	Pulp Mills	7.358	113.2	3.24	49.9
327	Nonmetallic Mineral Products	7.28	17.64	4.03	9.77
331	Primary Metals	7.19	19.90	2.69	7.46
32411	Petroleum Refineries	7.13	59.92	1.53	12.92
31131	Sugar Manufacturing	6.87	31.3	2.67	12.2
324	Petroleum and Coal Products	6.75	54.57	1.52	12.32
331521	Aluminum Die-Casting Foundries	6.68	9.8	3.34	4.9
3112	Grain and Oilseed Milling	6.62	17.55	2.15	5.71
322121	Paper Mills, except Newsprint	6.54	35.3	3.63	19.6
331524	Aluminum Foundries, except Die-Casting	6.50	8.36	3.37	4.34
331316	Aluminum Extruded Products	5.84	8.6	1.7	2.5
322	Paper	5.81	28.9	2.75	13.7
325188	Other Basic Inorganic Chemicals	5.68	19.02	3.21	10.75
32741	Lime	5.17	120.1	3.26	75.8
325	Chemicals	5.16	15.22	2.77	8.17
3212	Veneer, Plywood, and Engineered Woods	4.68	17.6	1.81	6.8
322122	Newsprint Mills	4.53	40.8	2.32	20.9
32511	Petrochemicals	4.33	39.60	1.80	16.47
3114	Fruit and Vegetable Preserving and Specialty Foods	4.10	5.5	2.08	2.8
325192	Cyclic Crudes and Intermediates	3.80	8.8	2.20	5.1
3315	Foundries	3.69	8.30	2.07	4.67

TABLE 1.7: Energy intensity of 2006 (Thousand BTUs per \$ of Value Added and Shipments) <sup>2/2</sup>

331511	Iron Foundries	3.6	12.6	1.86	6.51
324199	Other Petroleum and Coal Products	3.44	158.50	1.14	52.70
313	Textile Mills	3.14	8.6	1.49	4.1
3312	Steel Products from Purchased Steel	3.023	6.51	1.14	2.47
3115	Dairy Products	2.94	4.3	0.89	1.3
314	Textile Product Mills	2.93	4.6	1.15	1.8
3116	Animal Slaughtering and Processing	2.81	4.38	1.02	1.59
32731	Cements	2.74	52.5	1.78	34
3314	Nonferrous Metals, except Aluminum	2.69	9.20	0.84	2.88
311	Food	2.68	5	1.18	2.2
331112	Electrometallurgical Ferroalloy Products	2.12	46.71	1.02	22.64
321	Wood Products	2.03	10.54	0.782	4.05
332	Fabricated Metal Products	1.57	2.59	0.78	1.29
326	Plastics and Rubber Products	1.40	3.71	0.64	1.70
321113	Sawmills	1.31	15.20	0.43	5.03
3219	Other Wood Products	1.21	5.68	0.54	2.53
325992	Photographic Film, Paper, Plate, and Chemicals	.95	3.8	.6	2.4
3121	Beverages	0.94	2.35	0.43	1.07
336	Transportation Equipment	0.88	1.69	0.311	0.59
335	Electrical Equip., Appliances, and Components	0.86	2.13	0.38	0.94
336111	Automobiles	0.80	1.5	0.21	0.4
336112	Light Trucks and Utility Vehicles	0.75	1.3	0.17	0.3
323	Printing and Related Support	0.68	1.5	0.45	1
312	Beverage and Tobacco Products	0.52	1.37	0.33	0.88
315	Apparel	0.5	1	0.25	0.5
333	Machinery	0.49	1.2	0.24	0.6
316	Leather and Allied Products	0.36	1.1	0.2	0.6
334413	Semiconductors and Related Devices	0.36	1.21	0.27	0.91
3364	Aerospace Product and Parts	0.35	0.91	0.15	0.40
3254	Pharmaceuticals and Medicines	0.34	0.68	0.26	0.51
337	Furniture and Related Products	0.31	1.11	0.17	0.61
325412	Pharmaceutical Preparation	0.29	0.6	0.24	0.5
336411	Aircraft	0.24	0.6	0.08	0.2
339	Miscellaneous	0.227	0.6	0.15	0.4
334	Computer and Electronic Products	0.223	0.704	0.12	0.40
3122	Tobacco	0.075	0.3	0.075	0.3
327212	Other Pressed and Blown Glass and Glassware		40.80		24.89



Table 1.8: Economic variables

Variables	Source	Units	Time Period	Matches for	
				MECS and NGI	MECS and TEI
Capital expenditure	Census annual survey manufacturers	Millions of \$	1997-2011	78	79
Industrial production	Board of Governors of the Federal Reserve System	Index: 2007=100	1997-2013	78	79
Employment	Quarterly Census of Employment and Wages	Thousands	1997-2012	78	79
Imports	U.S. International Trade Commission	Billions of \$	1997-2013	75	76
Exports	U.S. International Trade Commission	Billions of \$	1997-2013	75	76

NGI : Natural Gas intensity;

TEI : Total Energy intensity.

MECS : Manufacturing Energy Consumption Survey.

TABLE 1.9: Estimation results for employment

Estimation method	GMM-IV (Arellano-Bond)			
Energy Intensity measure	Natural gas per \$ of Value added	Natural gas per \$ of Shipments	Total energy per \$ of Value added	Total energy per \$ of Shipments
$Employment_{i,t-1}$	0.566*** (6.48)	0.636*** (10.53)	0.564*** (4.84)	0.591*** (5.35)
$(NG^{USA}/NG^{EUR})_t$	-0.0000 (-0.65)	-0.0002 (-0.64)	-0.0001 (-1.17)	-0.0005 (-1.29)
$(NG^{USA}/NG^{EUR})_{t-1}$	-0.0002** (-2.32)	-0.0009** (-2.26)	-0.0003** (-2.39)	-0.0007** (-2.38)
Time fixed effects	Yes	Yes	Yes	Yes
Sectors	78		79	
Observations	1074		1088	
Time Period	1999-2012		1999-2012	
Total elasticity	-0.0021	-0.0038	-0.0085	-0.0103
Growth_rate <sub>2006-2013</sub>	0.14	0.25	0.56	0.67
Number of instruments	28			
Hansen J statistic	13.13	10.16	14.47	13.60
	<i>No Reject H<sub>0</sub></i>			
Cross sectional independence test : Pesaran	(-1.523)	(-1.529)	(-1.639)	(-1.654)*
Cross sectional independence test : Frees	(1.114)	(1.120)	(1.127)	(1.315)

Note : t-stat are in (); \*, \*\* and \*\*\* denote the significance levels at 10%, 5%, 1%, respectively.

TABLE 1.10: Estimation results for industrial production

Estimation method	GMM-IV (Arellano-Bond)			
Energy Intensity measure	Natural gas per \$ of Value added	Natural gas per \$ of Shipments	Total energy per \$ of Value added	Total energy per \$ of Shipments
$Indus\_produc_{i,t-1}$	0.867*** (6.28)	0.868*** (6.29)	0.853*** (5.96)	0.850*** (6.04)
$(NG^{USA}/NG^{EUR})_t$	-0.0006*** (-4.16)	-0.0023** (-3.71)	-0.0004* (-1.93)	-0.0013** (-1.99)
$(NG^{USA}/NG^{EUR})_{t-1}$	-0.0008*** (-11.46)	-0.0027*** (-8.20)	-0.0005** (-2.26)	-0.0010 (-1.38)
Time fixed effects	Yes	Yes	Yes	Yes
Sectors	78		79	
Observations	1170		1185	
Time Period	1999-2013		1999-2013	
Total elasticity	-0,041	-0,057	-0,044	-0,054
Growth.rate <sub>2006-2013</sub>	2,68	3,76	2,86	3,52
Number of instruments	31			
Hansen J statistic	15.17	15.21	15.04	15.02
	<i>No Reject H<sub>0</sub></i>			
Cross sectional independence test : Pesaran	(-1.416)	(-1.415)	(-1.430)	( -1.447)
Cross sectional independence test : Frees	(0.812)	(0.956)	(0.966)	(0.964)

Note : t-stat are in (); \*, \*\* and \*\*\* denote the significance levels at 10%, 5%, 1%, respectively.

TABLE 1.11: Estimation results for exports

Estimation method	GMM-IV (Arellano-Bond)			
Energy Intensity measure	Natural gas per \$ of Value added	Natural gas per \$ of Shipments	Total energy per \$ of Value added	Total energy per \$ of Shipments
$Exp_{i,t-1}$	0.679*** (6.20)	0.657*** (6.04)26.77**	0.682*** (4.30)	0.654*** (4.63)
$(NG^{USA} // NG^{EUR})_{t,97-05}$	0.0003 (0.92)	0.0012 (0.86)	0.0006** (1.87)	0.0021* (2.58)
$(NG^{USA} // NG^{EUR})_{t,06-2013}$	0.0003 (0.73)	0.0010 (0.66)	0.0007 (1.73)	0.0024* (1.91)
$(NG^{USA} // NG^{EUR})_{t-1,97-05}$	-0.0005*** (-3.46)	-0.0013 (-1.45)	-0.0006** (-2.11)	-0.0019** (-2.01)
$(NG^{USA} // NG^{EUR})_{t-1,06-2013}$	-0.0010*** (-3.83)	-0.0027* (-1.82)	-0.0009** (-2.28)	-0.0024* (-1.95)
Structural break	Yes	Yes	No	No
Time fixed effects	Yes	Yes	Yes	Yes
Sectors	75		76	
Observations	1125		1140	
Time period	1999-2013		1999-2013	
Total elasticity	-0.010	-0,011	-0.014	-0.035
Growth_rate <sub>2006-2013</sub>	0.68	0.76	0.90	2.30
Number of instruments	33			
Equality test of the coefficients	<i>Reject H<sub>0</sub></i>	<i>Reject H<sub>0</sub></i>	<i>No Reject H<sub>0</sub></i>	<i>No Reject H<sub>0</sub></i>
Hansen J statistic	11.68	9.65	38.90	13.54
	<i>No Reject H<sub>0</sub></i>			
Cross sectional independence test : Pesaran	(-1.214)	(-1.216)	(-1.216)	(-1.220)
Cross sectional independence test : Frees	(1.011)	(0.986)	(1.235)*	(1.156)

Note : t-stat are in ( ) ; \* , \*\* and \*\*\* denote the significance levels at 10% , 5% , 1% , respectively. Here we test the parameters null hypothesis of equality of the for the period 1997-2005 and 2006-2013. The rejection of  $H_0$  means that the parameters are different for the two periods. It proves the existence of a structural break.

TABLE 1.12: Estimation results for imports

Estimation method	GMM-IV (Arellano-Bond)			
Energy Intensity measure	Natural gas per \$ of Value added	Natural gas per \$ of Shipments	Total energy per \$ of Value added	Total energy per \$ of Shipments
$Imp_{i,t-1}$	0.517*** (2.71)	0.483** (2.55)	0.459** (2.57)	0.416** (2.46)
$(NG^{USA} // NG^{EUR})_{t,97-05}$	0.0004 (0.56)	-0.0002 (-0.06)	0.0004 (0.75)	-0.0000 (-0.02)
$(NG^{USA} // NG^{EUR})_{t,06-2013}$	0.0005 (0.71)	0.0001 (0.05)	0.0006 (0.98)	0.0003 (0.21)
$(NG^{USA} // NG^{EUR})_{t-1,97-05}$	0.0011*** (2.79)	0.0047** (2.11)	0.0007** (1.99)	0.0018 (1.49)
$(NG^{USA} // NG^{EUR})_{t-1,06-2013}$	0.0015*** (3.49)	0.0059*** (2.65)	0.0010*** (2.62)	0.0025 (1.87)
Structural break	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	No
Sectors	78		79	
Observations	1125		1140	
Time period	1999-2012		1999-2012	
Total elasticity	0.010	0.017	0.025	
Growth_rate <sub>2006-2013</sub>	-0.71	-1.11	-1.65	
Number of instruments	61			
Equality test of the coefficients	Reject $H_0$	Reject $H_0$	Reject $H_0$	No Reject $H_0$
Hansen J statistic	50.56	51.30	50.69	50.88
	No Reject $H_0$			
Cross sectional independence test : Pesaran	(-1.217)	(-1.210)	(-1.320)	(-1.125)
Cross sectional independence test : Frees	(1.023)	(1.115)	(1.116)	(1.119)

Note : t-stat are in (); \*, \*\* and \*\*\* denote the significance levels at 10%, 5%, 1%, respectively. Here we test the parameters null hypothesis of equality of the for the period 1997-2005 and 2006-2013. The rejection of  $H_0$  means that the parameters are different for the two periods. It proves the existence of a structural break.

TABLE 1.13: Comparison of estimators for exports (Nickell bias)

Estimation method	MCO	Within	Arellano-Bond	Anderson-Hsiao
Energy Intensity measure	Natural gas per \$ of Value added			
$Exp_{i,t-1}$	0.996*** (237.75)	0.889*** (40.00)	0.740 *** (7.96 )	0.714 (0.82)
$(NG^{USA} // NG^{EUR})_t$	0.0007** (5.11)	0.0010*** (5.45)	-0.0005 (-1.46)	-0.00005 (-0.04)
$(NG^{USA} // NG^{EUR})_{t-1}$	-0.00079*** (-5.55)	-0.0006426*** (-4.00)	-0.0010*** (-3.43)	-0.0010 (-0.80)
Constant	0.121 (1.34 )	2.327*** (4.90)	5.894*** (2.85)	0.018 (0.32)
Time fixed effects	No	Yes		
Sectors	75			
Observations	1200		1125	
Time period	1998-2013		1999-2013	
Number of instruments	0		80	17

Note : t-stat are in ( ) ; \*, \*\* and \*\*\* denote the significance levels at 10%, 5%, 1%, respectively. Theoretically the estimator of Anderson-Hsiao underestimates the coefficient of the lagged variable and the OLS overestimates it. The Arellano-Bond estimation must be between them. We are in this case, confirming the robustness of our results. The estimator within meanwhile suffers from a bias known as Nickell bias.

TABLE 1.14: Long-term elasticities (Thousand Btus per \$ of Value Added)  $1/2$ 

Industry	IP	Ca	Emp	Exp	Imp
Nitrogenous Fertilizers	-3.548	-1.668	-0.199	-0.905	0.944
Alkalies and Chlorine	-0.512	-0.241		-0.131	0.136
Carbon Black	-0.374	-0.176		-0.095	0.100
Flat Glass	-0.348	-0.164	-0.019	-0.089	0.093
Glass Containers	-0.224	-0.106	-0.013	-0.057	0.060
Ethyl Alcohol	-0.211	-0.099	-0.012	-0.054	0.056
Gypsum	-0.195	-0.092	-0.011	-0.050	0.052
Other Basic Organic Chemicals	-0.186	-0.087	-0.010	-0.047	0.049
Industrial Gases	-0.182	-0.086	-0.010	-0.046	0.048
Plastics Materials and Resins	-0.181	-0.085	-0.010	-0.046	0.048
Phosphatic Fertilizers	-0.181	-0.085	-0.010	-0.046	0.048
Secondary Smelting and Alloying of Aluminum	-0.163	-0.077	-0.009	-0.042	0.043
Wet Corn Milling	-0.150	-0.070	-0.008	-0.038	0.040
Iron and Steel Mills	-0.140	-0.066		-0.036	0.037
Paperboard Mills	-0.131	-0.061	-0.007	-0.033	0.035
Synthetic Rubber	-0.124	-0.058	-0.007	-0.032	0.033
Alumina and Aluminum	-0.123	-0.058	-0.007	-0.031	0.033
Noncellulosic Organic Fibers	-0.119	-0.056		-0.030	0.032
Aluminum Sheet, Plate and Foils	-0.114	-0.054	-0.006	-0.029	0.030
Mineral Wool	-0.103	-0.048	-0.006	-0.026	0.027
Glass Products from Purchased Glass	-0.093	-0.044	-0.005	-0.024	0.025
Pulp Mills	-0.087	-0.041	-0.005	-0.022	0.023
Nonmetallic Mineral Products	-0.086	-0.041	-0.005	-0.022	0.023
Primary Metals	-0.085	-0.040	-0.005	-0.022	0.023
Petroleum Refineries	-0.084	-0.040	-0.005	-0.022	0.022
Sugar Manufacturing	-0.081	-0.038	-0.005	-0.021	0.022
Petroleum and Coal Products	-0.080	-0.038	-0.004	-0.020	0.021
Aluminum Die-Casting Foundries	-0.079	-0.037			
Grain and Oilseed Milling	-0.078	-0.037	-0.004	-0.020	0.021
Paper Mills, except Newsprint	-0.077	-0.036	-0.004	-0.020	0.021
Aluminum Foundries, except Die-Casting	-0.077	-0.036	-0.004	-0.020	0.020
Aluminum Extruded Products	-0.069	-0.033		-0.018	0.018
Paper	-0.069	-0.032	-0.004	-0.018	0.018
Other Basic Inorganic Chemicals	-0.067	-0.032		-0.017	0.018
Lime	-0.061	-0.029	-0.003	-0.016	0.016
Chemicals	-0.061	-0.029	-0.003	-0.016	0.016
Veneer, Plywood, and Engineered Woods	-0.055	-0.026	-0.003	-0.014	0.015
Newsprint Mills	-0.054	-0.025	-0.003	-0.014	0.014
Petrochemicals	-0.051	-0.024	-0.003	-0.013	0.014
Fruit and Vegetable Preserving and Specialty Foods	-0.048	-0.023	-0.003	-0.012	0.013
Cyclic Crudes and Intermediates	-0.045	-0.021		-0.011	0.012
Foundries	-0.044	-0.021	-0.002	-0.011	0.012
Iron Foundries	-0.043	-0.020	-0.002	-0.011	0.011
Other Petroleum and Coal Products	-0.041	-0.019	-0.002		

TABLE 1.15: Long-term elasticities (Thousand Btus per \$ of Value Added) <sup>2/2</sup>

Steel Products from Purchased Steel	-0.036	-0.017	-0.002	-0.009	0.010
Dairy Products	-0.035	-0.016	-0.002	-0.009	0.009
Textile Product Mills	-0.035	-0.016	-0.002	-0.009	0.009
Animal Slaughtering and Processing	-0.033	-0.016	-0.002	-0.008	0.009
Cements	-0.032	-0.015	-0.002	-0.008	0.009
Nonferrous Metals, except Aluminum	-0.032	-0.015	-0.002	-0.008	0.008
Food	-0.032	-0.015	-0.002	-0.008	0.008
Electrometallurgical Ferroalloy Products	-0.025	-0.012		-0.006	0.007
Wood Products	-0.024	-0.011	-0.001	-0.006	0.006
Fabricated Metal Products	-0.019	-0.009	-0.001	-0.005	0.005
Plastics and Rubber Products	-0.017	-0.008	-0.001	-0.004	0.004
Sawmills	-0.016	-0.007	-0.001	-0.004	0.004
Other Wood Products	-0.014	-0.007	-0.001	-0.004	0.004
Photographic Film, Paper, Plate, and Chemicals	-0.011	-0.005	-0.001	-0.003	0.003
Beverages	-0.011	-0.005	-0.001	-0.003	0.003
Transportation Equipment	-0.010	-0.005	-0.001	-0.003	0.003
Electrical Equipment, Appliances, and Components	-0.010	-0.005	-0.001	-0.003	0.003
Automobiles	-0.010	-0.004	-0.001	-0.002	0.003
Light Trucks and Utility Vehicles	-0.009	-0.004	-0.001		
Printing and Related Support	-0.008	-0.004	0.000	-0.002	0.002
Beverage and Tobacco Products	-0.006	-0.003	0.000	-0.002	0.002
Apparel	-0.006	-0.003	0.000	-0.002	0.002
Machinery	-0.006	-0.003	0.000	-0.001	0.002





## Chapter 2

# Carbon Curse in Developed Countries

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### 2.1 Introduction

In early 2019, China announced the discovery of oil reserves that could trigger a surge in shale drilling. This discovery confirms estimates by the U.S. Energy Information Administration that China has abundant shale gas and shale oil potential. What could be the consequences of the increase in resource abundance on greenhouse gas (GHG) emissions? In the specific case of China, more resources induce more growth and hence more energy consumption. However, oil may substitute coal, which could decrease CO<sub>2</sub> emissions. The effect of such discoveries in natural resources on CO<sub>2</sub> emissions may be crucial since world emissions are still increasing, despite international mitigation commitments like the *Paris Agreement* (2016). The continuous rise in emissions is due mainly to industrial production, and transport and heating in addition to the energy mix. The more fossil fuels remain important in the energy mix, the higher the CO<sub>2</sub> emissions will be. Regulating these sources of emissions may harm growth, competitiveness, mobility, and individuals' purchasing power. These potential consequences explain the public opposition to environmental regulation and the reluctance of many countries to take strong commitments. In this paper, we argue that in addition to the usual drivers of CO<sub>2</sub> emissions, natural resource abundance plays a crucial role. Indeed, natural resources and the associated sectors, like extraction and energy production (refining), together with the use of fossil fuels cause pollution. Friedrichs and Inderwildi (2013) defined the link between fossil fuel resources and CO<sub>2</sub> emissions as the *carbon curse assumption*: countries rich in coal, oil, and gas emit more CO<sub>2</sub> to generate the same amount of economic

output as countries lacking in fossil fuels. Thus, a fossil resource-rich country tends to be a *rich* country with significant CO<sub>2</sub> emissions. The relationships between resources and economic growth have already been widely discussed in the literature. Studies conclude that there are links between natural resources and economic growth (resource curse) and interactions between pollution levels and economic growth (the Environmental Kuznets Curve “EKC”). Our work is at the crossroads of these two fields since we investigate more generally the relationship between natural resources and CO<sub>2</sub> emissions to test an *extended* carbon curse assumption.<sup>4</sup>

We aim at assessing whether a country rich in natural resources is more polluting than another country and whether resource abundance affects all sectors of the economy. Our objective is to contribute to the debate on climate change mitigation by measuring the consequences of abundance in natural resources on emissions at different levels: national and sectoral. Our empirical analysis relies on extensive panel data covering 29 countries and seven sectors, over the 1995–2009 period. The combination of these data allows for an original analysis that sheds light on observations at the macroeconomic level by highlighting mechanisms that have hitherto been ignored at the sectoral level. To the best of our knowledge, this study is the first to go beyond a simple descriptive statistical analysis by proposing econometric tests of the carbon curse assumption.

This study is related to two strands of the literature mentioned above: the first strand investigates the link between economic growth and pollution emissions (EKC), and the second analyses the interactions between natural resources and economic growth (resource curse).

The first strand, the environmental consequences of economic growth, has been the subject of intense research over the past few decades. Several pieces of empirical work have suggested that there is an inverted U-shaped relationship between economic growth, usually measured in terms of income per capita, and pollution emission (EKC). At the first stage of economic growth, environmental degradation increases as per capita income increases, but begins to decrease as rising per capita income passes beyond a turning point. According to the EKC hypothesis, economic growth could be the remedy to environmental problems in the long-term. Since the beginning of the 1990s, the EKC has become an independent and essentially empirical research domain, following the work of Grossman and Krueger (1995), Shafik and Bandyopadhyay (1992) Panayotou et al. (1993), Selden and Song (1994), and Galeotti (2007). However, the conclusions are ambiguous. On the one hand, some research has confirmed the existence of an EKC for different measurements of environmental

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4. According to Friedrichs and Inderwildi (2013), the carbon curse results from the relationship between CO<sub>2</sub> emissions and the abundance of fossil energy resources. We extend this analysis by adding mineral resources in the definition of the abundance variable. The results related to the standard definition of the carbon curse are presented in Tables 2.9 and 2.10.

degradation; see Panayotou et al. (1993) and Selden and Song (1994). On the other hand, several studies affirm that there is no evidence of the EKC and, rather, find a monotonically increasing or decreasing relationship between pollution and per capita income, e.g. Holtz-Eakin and Selden (1995), Torras and Boyce (1998), Hettige et al. (2000), De Bruyn et al. (1998) and Roca et al. (2001). The sources of discrepancies between the empirical results stem mainly from the nature and the level of aggregation of the data (time series, cross-section, or panel) and the pollutant under consideration. Nevertheless, studies on CO<sub>2</sub> tend to show an ever-increasing relationship between GDP and emissions.

The second strand of the literature analyzes the interactions between growth and natural resources. Following the seminal work of Sachs and Warner (1995), a huge body of 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. Five major transmission channels have been identified to explain the resource curse. The most popular is the “Dutch disease”, which has been widely documented in the literature (see for example Corden (1984); Krugman (1987); Bruno and Sachs (1982); Torvik (2001); Matsen and Torvik (2005)). This refers to the deterioration in terms of trade that results from the real exchange rate appreciation following a resource boom. This shift in terms of trade has a negative impact on non-resource sectors. A second channel is the negative effect of natural resources on education. Following Gylfason (2001) and Sachs and Warner (1995), natural resource abundance increases the agents’ opportunity cost of human capital investment. The third channel refers to institutional quality. Resources may induce rent-seeking behaviors, which reduce institutional quality (a major determinant of economic growth) through corruption or armed conflict (see Jensen and Wantchekon (2004); Robinson et al. (2006); Adani et al. (2014)). Natural resources may also crowd out physical capital investment (Sachs and Warner (1995)). A resource boom implies a shift in the distribution of production factors from the secondary and tertiary sectors to the primary sector. As the manufacturing and tertiary sectors are more likely to exhibit increasing returns to scale and positive externalities than the primary sector, this shift will reduce productivity and the profitability of investment. Lastly, the volatility in resource prices could increase macroeconomic instability, which in turn inhibits growth (Van der Ploeg and Poelhekke (2009)).

We are interested in the intersection between these two branches. Empirical studies of the resource curse conclude that resources may have a positive or negative impact on economic growth, while works on the EKC find an increasing or decreasing relationship between economic growth and CO<sub>2</sub> emissions. In the end, these two literature strands do not allow for a simple understanding of

the links between natural resources and GHG emissions. Thus, we deeply analyze the interactions between natural resources and pollution and investigate empirically the carbon curse assumption to check whether a higher abundance of natural resources implies higher carbon intensity. The main intuitions for the mechanisms at stake for a carbon curse are as follows. First is a *composition effect* induced by the predominance of fossil fuel sectors which massively emit CO<sub>2</sub>. Second are the *crowding out effects* in the energy generation sector, which forms a barrier to the development of renewable energy sources. Third are the *spillover effects* in other sectors of the economy, which are combined with less stringent policies. According to Friedrichs and Inderwildi (2013), very few resource-rich countries avoid the carbon curse, except for those suffering from the resource curse. However, the literature on EKC and the resource curse often points out the crucial role of economic development and the quality of institutions. By focusing on a group of developed countries, we highlight the importance of a novel argument based on resource abundance.

While Friedrichs and Inderwildi (2013)'s results are based on descriptive statistics with cross-sectional data, we apply econometric methods to provide detailed evidence for the carbon curse assumption and explain its mechanisms. We consider both macroeconomic and sectoral data for a group of developed countries. Our database includes 29 developed countries, including the BRIC, and spans over 15 years (1995–2009); it reveals considerable heterogeneity between the countries. Our sectoral data consider seven sectors. This magnitude of data, both geographically and temporally, makes it possible to measure the complexity of the carbon curse hypothesis better.

Indeed, we find that the interaction between CO<sub>2</sub> intensity of GDP and resource abundance is non-monotonous.<sup>5</sup> More specifically, our results show that there is a U-shaped relationship between CO<sub>2</sub> intensity and resource endowment at the country level: above a turning point, the more natural resource-rich a country is, the more it will emit CO<sub>2</sub> per unit of GDP. We also find that national CO<sub>2</sub> intensity is explained by the energy mix, environmental policy stringency, and technological level. Thus, to explain this U-shaped relationship at the country level, we rely on a sectoral analysis using sectoral CO<sub>2</sub> emissions intensity. The results show that abundance has a different impact on the sectoral CO<sub>2</sub> intensity across sectors and that there exist spillover effects among all sectors (even in the services sector). Interestingly, resource-rich and relatively resource-poor countries show opposite results.

The remainder of the paper is structured as follows. In section 2, we develop a simple accounting

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5. By contrast, Wang et al. (2019) find evidence for a positive correlation between natural resource dependence and carbon intensity among China's provinces over 2003–2016. On the other hand, Balsalobre-Lorente et al. (2018) show that for five European countries (France, Germany, Italy, Spain, and the United Kingdom), more natural resource abundance helped control CO<sub>2</sub> emissions for the period 1985–2016.

decomposition to explain the carbon curve assumption. Section 3 describes the data used. Section 4 presents the methodological approach and Section 5, the empirical findings. The interpretation of the results and robustness checks are presented in Section 6, and Section 7 concludes.

## 2.2 A simple decomposition

Drawing on the works of Grossman and Krueger (1995) and Copeland and Taylor (2004), we first propose a simple accounting framework. The objective is to break down changes in the CO<sub>2</sub> intensity into components that reflect changes in energy consumption, energy intensity, and industrial structure of the overall economy. This type of breakdown has been largely used in the EKC literature. We build on these previous works and propose a new decomposition for CO<sub>2</sub> emissions at the crossroads of the EKC and carbon curve literature.

We focus on the main factors that could explain the total changes in CO<sub>2</sub> intensity (CO<sub>2</sub>/GDP). Total CO<sub>2</sub> emissions can be measured by the following decomposition:

$$CO_2 = \sum_i \sum_h \frac{\phi_{ih} E_{ih}}{E_i} \frac{E_i}{VA_i} \frac{VA_i}{GDP} GDP, \quad (2.1)$$

where  $E_{ih}$  is the consumption of energy of type  $h$  in sector  $i$ ;  $\phi_{ih}$  is the net CO<sub>2</sub> emissions intensity from energy  $h$  in sector  $i$ ;  $E_i$  is the total energy consumption in sector  $i$ ;  $VA_i$  refers to economic output in sector  $i$  (Value Added);  $GDP$  is the total economic output.  $\phi_{ih}$  depends on the type of energy used (*i.e.* gas, coal, oil, biomass, renewables, and others) but also depends on the sector's decarbonation technology (CCS technology, for instance).

We consider two sources of energy: fossil energy ( $f$ ) and renewables ( $r$ ) with  $\phi_{if} > \phi_{ir} \geq 0$ . We also consider seven sectors ( $i = 1, \dots, 7$ ): mining, services, agriculture, transport, manufacturing, construction, and electricity, respectively.

Dividing both sides of Eq. (2.1) by  $GDP$  gives Eq. (2.2) which measures the overall CO<sub>2</sub> intensity  $I_\varepsilon = CO_2/GDP$ :<sup>6</sup>

$$I_\varepsilon = \sum_{i=1}^7 \sum_{h=r,f} \phi_{ih} U_{ih} \cdot I_i \cdot S_i, \quad (2.2)$$

where  $U_{ih}$  is the share of consumption of energy source  $h$  in sector  $i$  ( $\frac{E_{ih}}{E_i}$ ),  $I_i$  is the energy intensity ( $\frac{E_i}{VA_i}$ ), and  $S_i$  is the share of sector  $i$ 's output in the overall economy ( $\frac{VA_i}{GDP}$ ).

6. At the sectoral level, the breakdown simply gives  $\frac{CO_{2i}}{VA_i} = \sum_{h=r}^f \frac{\phi_{ih} E_{ih}}{E_i} \frac{E_i}{VA_i}$ .

The net emission rate per unit of energy used,  $\phi_{ih}$ , should depend on the level of technology, which itself is influenced by the stringency of the environmental regulation. As in the EKC literature, the net emission rate is supposed to be negatively related to the environmental regulation stringency. If the stringency is also negatively influenced by the resource abundance, there will be an impact on the net emission rate.

This simple accounting decomposition emphasizes the carbon curse mechanisms, where resource abundance explains the share of the mining sector in total GDP ( $S_1$ ), which should influence the energy mix  $\frac{E_f}{E}$  (where for  $h = r, f$ ,  $E_h = \sum_{i=1}^7 E_{ih}$  and  $E = \sum_{h=r,f} E_h$ ), the share  $U_{if}$  and the energy intensity  $I_i$ :

- a *composition effect*, induced by the share of the mining sector in the GDP ( $S_1$ ), given that this sector is a massive CO<sub>2</sub> emitter;
- a *crowding out effect* in the energy generation process, forming a barrier to the development of renewable energy sources. This implies a high share of the consumption of fossil energy in all sectors (high  $U_{if}, \forall i$ ) compared to renewable energies (low  $U_{ir}, \forall i$ );<sup>7</sup>
- *spillover effects* in other sectors of the economy (high  $I_i, \forall i$ ) combined with less stringent policies (high  $\phi_{ih}, \forall i, h$ ).

At the macroeconomic level, if we assume (for simplicity) that renewable energies are non-polluting ( $\phi_{ir} = 0$ ), we obtain:

$$\frac{CO_2}{GDP} = \phi_f \frac{E_f}{E} \frac{E}{GDP}, \quad (2.3)$$

which gives, in terms of growth rate (taking logs and differentiating):

$$\widehat{\frac{CO_2}{GDP}} = \widehat{\phi_f} + \widehat{\frac{E_f}{E}} + \widehat{\frac{E}{GDP}}.$$

Growth of emissions intensity could be explained by the technical progress in the fossil fuel sector  $\widehat{\phi_f}$ , the variation in the fossil component of the energy mix  $\widehat{\frac{E_f}{E}}$ , and in the energy intensity of GDP  $\widehat{\frac{E}{GDP}}$ . The carbon curse means that we could have an increase in CO<sub>2</sub> emissions  $\widehat{\frac{CO_2}{GDP}} > 0$ , despite a decrease in the energy intensity ( $\widehat{\frac{E}{GDP}} < 0$ ) or a decrease in the emission rate  $\widehat{\phi_f} < 0$  (green innovations or technical progress). Finally, if the new fossil deposits are less emitting (discovery of gases whose exploitation replaces coal), the change in the energy mix reduces CO<sub>2</sub> emissions.

7. Johnsson et al. (2019) show that fossil resource-rich countries have experienced a large increase in primary energy demand from fossil fuels, but only a moderate or no increase in primary energy from renewables.

An important result to highlight is the interdependence of the components in this accounting relationship. The size of the fossil fuel sector  $\frac{E_f}{E}$  probably influences the severity of environmental regulation. However, this consequence of fossils on regulation can be negative or positive depending on external parameters such as the level of development, the size of the country, and household preferences. This means that when fossil resources increase  $\widehat{\frac{E_f}{E}} > 0$ , emissions intensity can also increase  $\widehat{\frac{CO_2}{GDP}} > 0$  or may decrease if the emission rate decreases  $\widehat{\phi}_f < 0$  (due to stricter regulation and *green* technological progress) or if the energy intensity of the GDP decreases, for example.

This simple decomposition approach identifies a set of possible factors that explain the CO<sub>2</sub> intensity, but accounting for decomposition alone does not explain correlation much (*a fortiori* causality). Moreover, it is essentially descriptive and does not take into account other factors that may influence the results, such as corruption or weather. To do so, we test a broader explanation of the evolution of the CO<sub>2</sub> intensity empirically, using an econometric approach that includes the set of fundamental variables identified in the accounting decomposition, to which we add variables which are the subject of consensus in the literature. Basically, we go beyond simple accounting decomposition and estimate reduced-form equations that link the level of CO<sub>2</sub> intensity to fossil resource abundance and other determinants.<sup>8</sup>

## 2.3 Data

This study explores the linkages among renewable energy, environmental policy stringency, corruption, law and order, democracy, government stability, technological level, population density, urbanisation rate, natural resource abundance, and CO<sub>2</sub> emissions to assess the validity of the carbon curse. Thus, to conduct an in-depth analysis of this assumption, we rely on two databases. The first one allows to test the validity of a carbon curse by looking at the effect of natural resource abundance on the carbon intensity at the macroeconomic level. In a second step, we use a country sector database to refine the results by disentangling the overall country effect. Indeed, the disaggregated sectoral data allow for testing whether resource endowment alters the sector elasticity between resource-rich and resource-poor countries. In other words, we investigate if CO<sub>2</sub> efficiency of sectors differs between resource-rich and resource-poor countries. This approach of using two databases is not free of cost. To conduct a consistent analysis, we need to keep the same countries

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8. An empirical estimation of this decomposition (Ang's Divisia index for example) faces several methodological limitations and has been highlighted in many studies on the EKC. For a detailed presentation of the pros and cons of each approach, see De Bruyn (1997) and Stern (2002).



in our two datasets. But data availability at the sectoral level is restricted to OECD and BRIC countries and through time. As a result, we have a sample of 29 OECD and BRIC countries over the 1995–2009 period.<sup>9</sup> Consequently, our dataset only includes developed and emerging countries.

A key variable for our study is the measure of the resource stock. Until now, the literature relies on proxies for natural resource abundance because of the lack of appropriate data. The most-used proxy for abundance is the Sachs and Warner variable, which corresponds to the ratio of natural resource exports to GDP (Sachs and Warner (1995)). We argue that this proxy is an appropriate measure of the resource dependence, but not of abundance and it is potentially endogenous when used in the resource curse literature. For our study, we rely on the *resource abundance* variable from the World Bank data series (1997, 2006, 2011). The value of a country's stock of a non-renewable resource is measured as the present value of the stream of expected rents that may be extracted from the resource until it is exhausted (Lange et al. (2018)).<sup>10</sup> It avoids the endogeneity issue as Brunnschweiler and Bulte (2008), Ding and Field (2005), and Alexeev and Conrad (2009) have done already. However, does this variable offer a real improvement? The accuracy and reliability of the natural capital and, specifically, of the subsoil asset data were important concerns for the World Bank studies. Nevertheless, one might argue that data availability is conditional to a country's technological level. But data on natural resource wealth are probably independent of local issues, and exogenous enough for our study. Especially, fossil and mineral deposits which we focus on have been quite well explored and estimated due to the broad economic benefits they may confer (Karl (1997)). Moreover, the commitment of large multinational firms using a similar technical approach to collect their information regardless of the local political and technological conditions is conducive to the exogeneity of our resource stock variable.

Finally, the measure of resource abundance by the World Bank is innovative and gives a novel insight into the magnitude of the natural capital. It can be used as a measure for the value of subsoil assets (the subsoil wealth measure values the principal fossil and mineral stock present in a country) in US\$ for cross-country or panel datasets.

The economy-wide and sectoral datasets are described in subsections 2.3.1 and 2.3.2, respectively.

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9. The country-level dataset covers the 1995–2014 period. We conduct the same analysis over this extended sample and obtain qualitatively unchanged results; see section 2.6.

10. The fossil energy resources valued in the World Bank wealth accounts are petroleum, natural gas, and coal, while metals and minerals include bauxite, copper, gold, iron ore, lead, nickel, phosphate rock, silver, tin, and zinc.

### 2.3.1 The country level dataset

The country-level dataset covers yearly observations for 29 countries over the full spectrum from resource-rich to resource-poor countries among OECD and BRIC organizations for the 1995–2009 period. Overall, our sample accounts for almost 75% of the world CO<sub>2</sub> emissions. Hence, to assess the impact of resource endowment on CO<sub>2</sub> emissions, we collect variables that together cover relevant socioeconomic and climatic factors. Twelve variables for each country are taken into account.

Details and sources for these variables are given in Table 2.6 in Appendix A. Anthropogenic CO<sub>2</sub> emissions, resource abundance, GDP per capita (PPP adjusted), urbanisation rate, population density, and technological level approximated by the number of filed patents are taken from the World Bank. A patent is taken as an observation in the year in which it is filed in a national patent authority from the World Intellectual Property Organization (WIPO). Alternative energy use is measured as the share of clean and nuclear energy, in which clean energy is noncarbohydrate energy that does not produce carbon dioxide when generated. It includes hydropower, nuclear, geothermal, and solar power, among others. The OECD Environmental Policy Stringency Index (EPS) is a country-specific and internationally-comparable measure of the stringency of the environmental policy. Stringency is defined as the degree to which environmental policies put an explicit or implicit price on pollution or environmentally harmful behavior. The index is based on the degree of stringency of 14 environmental policy instruments primarily related to climate and air pollution. The indicator ranges from 0 (not stringent) to 6 (highest degree of stringency). Finally, climatic conditions are captured through cooling degree days (CDD) and heating degree days (HDD), taken from the Euro-Mediterranean Center for Climate Change. Heating and cooling degree days (HDD and CDD) index measure the heating and cooling needed to neutralize the deviation of surface temperature from a standard comfort level. HDD and CDD are conventionally measured as the annual sums of negative and positive deviations of daily mean surface temperatures from a reference standard of 18.3° Celsius.

Furthermore, we also recognize the key role institutions have to play in the reduction of pollution. In order to assess its role, we introduced institutional variables such as: corruption, democracy, law and order, and government stability. All these variables are from the International Country Risk Guide (ICRG) with the exception of the corruption variable.<sup>11</sup>

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11. The ICRG index comes from Political Risk Services Inc., a private firm that annually publishes the International Country Risk Guide (ICRG). The ICRG database provides a quantification of the political, economic and

### 2.3.2 Sector level dataset

A dataset of 28 countries<sup>12</sup> in 34 sectors of activity from 1995 to 2009 is built from the World Input-Output Database (WIOD) and World Bank database, which provides a solid basis for an insightful analysis of the heterogeneity of natural resources impacts on sectoral energy intensity. The WIOD is based on the national accounts which have been released as part of the European Commission's 7th Framework Program. The WIOD database has two main benefits in comparison to earlier available data sources. First, data process harmonization techniques have been implemented to guarantee international comparability of data. This ensures data quality and minimizes the risk of measurement errors. Second, WIOD provides sectoral price deflators, the use of which makes it possible to preserve important information and the heterogeneity of sectors in relation to price dynamics. This represents an improvement over the use of aggregated national price deflators.

By aggregating the sectoral database according to ISIC-rev2 classification, we obtain seven sectors, which allow for interpreting and comparing our results easily.

We also retain the same variables as in the country-level database but use sectoral data when they are available and relevant. Sectoral anthropogenic CO<sub>2</sub>, sectoral value added, and technological level are taken from the WIOD. Sectoral technology variable corresponds to the share, in percentage, of sector-specific working hours of high-skilled workers as compared to total sector-specific working hours. A relative increase in high-skilled working hours is considered to be equivalent to an improvement in sector-specific technology. The GHG policy stringency, natural resource abundance, and the climatic and socio-demographic variables are independent of the level of analysis.

### 2.3.3 Descriptive analysis

Although all countries in our sample are at an advanced stage of development, there are still economic and environmental heterogeneities. Table 2.1 provides descriptive statistics by variable of interest, while Tables 2.2 and 2.3 present the averages by country over 1995–2009, which is the

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financial risks in general. Government stability assesses the government's ability to carry out its declared programs and its ability to stay in office. The risk rating assigned is the sum of three subcomponents: government unity, legislative strength and popular support. Law and public order" is a unique component, but its two components are scored separately, with each component being scored from zero to three points. In assessing the "Law" element, the strength and neutrality of the legal system is taken into account, while the "Order" element is an assessment of popular respect for the law.

12. The countries are the same as in the country level database, except for Hungary because of the lack of data at the sectoral level.

common period with the sectoral dataset.<sup>13</sup> For consistency between country-level and sectoral estimates, we present the descriptive statistics, and in subsequent sections, the estimations.<sup>14</sup>

Table 2.1: Summary statistics

Variable	Mean	SD	Min.	Max.
CO <sub>2</sub> Intensity (kg/US\$)	0.34	0.16	0.11	1.1
Abundance (2005 US\$)	1.52.10 <sup>11</sup>	4.29.10 <sup>11</sup>	1	3.47.10 <sup>12</sup>
Environmental policy stringency (0;6)	1.53	0.85	0.33	4.07
Heating degree days (° .nb days)	12354.43	5689.74	0.02	23174.28
Cooling degree days (° .nb days)	2156.92	2573.21	19.36	11921
Technological level (nb filed patents)	22219	65563	3	384201
Alternative (% total energy use)	11.85	11.77	0	50.73
Corruption (-2,5;2,5)	0.86	0.98	-1.13	2.5

The average national CO<sub>2</sub> intensities of the GDP range from 0.15 (Brazil and Sweden) to 0.83 (Spain), while the share of alternative energies varies from 0.21% (Poland) to 47.12% (Sweden). Similarly, the corruption index ranges from -0.91 for Russia to 2.44 for Denmark and Finland (negative values denote high levels of corruption), and goes hand in hand with the distribution of environmental stringency. The technological level index is another important differentiation factor, with the largest value (Japan) being more than 1500 times higher than the lowest (Indonesia).

These descriptive statistics do not allow for simple correlations between variables. Indeed, in a counterintuitive way, Sweden and Brazil, for example, have the same CO<sub>2</sub> intensity while the latter is much richer in resources than the former. We also note that environmental stringency is probably not the main determinant of the CO<sub>2</sub> intensity of GDP: despite a much higher environmental severity and an apparently more favorable energy mix, Germany emits more CO<sub>2</sub> per unit of GDP than Turkey.

Belgium has nearly the same carbon intensity as Japan or the United Kingdom despite having much lower natural resource abundance over the period. There may be a historical influence in this case: Belgium was once a resource-rich country, but its fossil resources (mainly coal) have now depleted.

The heterogeneity of natural resource abundance indicates that the sample covers economies from natural resource-rich countries to natural resource-poor countries.

13. Table 2.1 shows the average of all variables for the 1995–2009 period and all countries. Table 2 shows the averages by country. The min and max of Table 1 are absolute minimum and maximum observed over all the data.

14. Section 2.6 provides a robustness test of the country-level estimation over the extended period of 1995–2014.

Table 2.2: Variable means by country (1/2)

Country	CO <sub>2</sub> Intensity (kg/US\$)	Abundance (2005 US\$)	Alternative energy (% of energy use)	Env. Stringency Index (0;6)
Australia	0.47	2.50.10 <sup>11</sup>	1.36	1.29
Austria	0.20	3.04.10 <sup>9</sup>	11	2.34
Belgium	0.28	4.43.10 <sup>6</sup>	21	1.47
Brazil	0.15	2.31.10 <sup>11</sup>	14.52	0.45
Canada	0.44	2.57.10 <sup>11</sup>	20.59	1.52
China	0.79	6.68.10 <sup>11</sup>	2.65	0.67
Czech Republic	0.51	1.98.10 <sup>9</sup>	12.16	1.53
Denmark	0.24	2.84.10 <sup>10</sup>	2.12	2.61
Finland	0.32	4.14.10 <sup>8</sup>	20.45	2.14
France	0.17	4.30.10 <sup>9</sup>	44.81	1.95
Germany	0.27	2.76.10 <sup>11</sup>	13.47	2.39
Greece	0.31	2.30.10 <sup>9</sup>	1.95	1.75
Hungary	0.29	8.72.10 <sup>9</sup>	14.33	1.62
India	0.37	2.49.10 <sup>11</sup>	2.53	0.59
Indonesia	0.21	2.14.10 <sup>11</sup>	5.95	0.45
Ireland	0.25	1.98.10 <sup>9</sup>	0.98	1.26
Italy	0.21	2.51.10 <sup>10</sup>	4.63	1.82
Japan	0.27	3.77.10 <sup>9</sup>	17.41	1.57
South Korea	0.42	4.98.10 <sup>8</sup>	15.70	1.78
Netherlands	0.27	2.71.10 <sup>10</sup>	1.52	2.08
Poland	0.54	2.77.10 <sup>10</sup>	0.21	1.46
Portugal	0.22	2.65.10 <sup>8</sup>	4.80	1.75
Russia	0.68	2.77.10 <sup>12</sup>	7.88	0.54
Slovakia	0.41	4.81.10 <sup>8</sup>	23.98	1.16
Spain	0.83	1.70.10 <sup>9</sup>	15.42	2.27
Sweden	0.15	1.84.10 <sup>9</sup>	47.12	2.15
Turkey	0.23	2.21.10 <sup>10</sup>	5.49	0.86
United-Kingdom	0.26	1.49.10 <sup>11</sup>	10.22	1.46
United-States	0.42	6.35.10 <sup>11</sup>	10.81	1.52

Table 2.3: Variable means by country (2/2)

Country	Heating DD (° .nb days)	Cooling DD (° .nb days)	Technological level (nb filed patents)	Corruption (-2,5;2,5)
Australia	4337	3095	2262	1.92
Austria	18494	531	2073	2
Belgium	11643	1112	604	1.36
Brazil	759	7000	3476	-0.03
Canada	20883	876	4221	2
China	10297	3527	71598	-0.43
Czech Republic	16848	767	625	0.37
Denmark	12116	519	1599	2.44
Finland	21426	407	2116	2.44
France	12069	1177	13759	1.34
Germany	15262	810	47222	1.91
Greece	9117	3385	408	0.47
Hungary	14092	1348	778	0.57
India	1750	11296	3646	-0.39
Indonesia	0.1	10710	204	-0.85
Ireland	10969	61	882	1.58
Italy	10984	1647	7968	0.44
Japan	8483	2600	351313	1.13
South Korea	10180	2126	90068	0.38
Netherlands	11729	416	2299	2.17
Poland	15959	999	2375	0.39
Portugal	5182	1317	168	1.19
Russia	21439	1085	22612	-0.91
Slovakia	16060	1082	214	0.24
Spain	10089	2652	2773	1.22
Sweden	17021	392	3321	2.27
Turkey	12926	2830	788	-0.25
United-Kingdom	11559	350	18967	2
United-States	11291	3109	177772	1.6

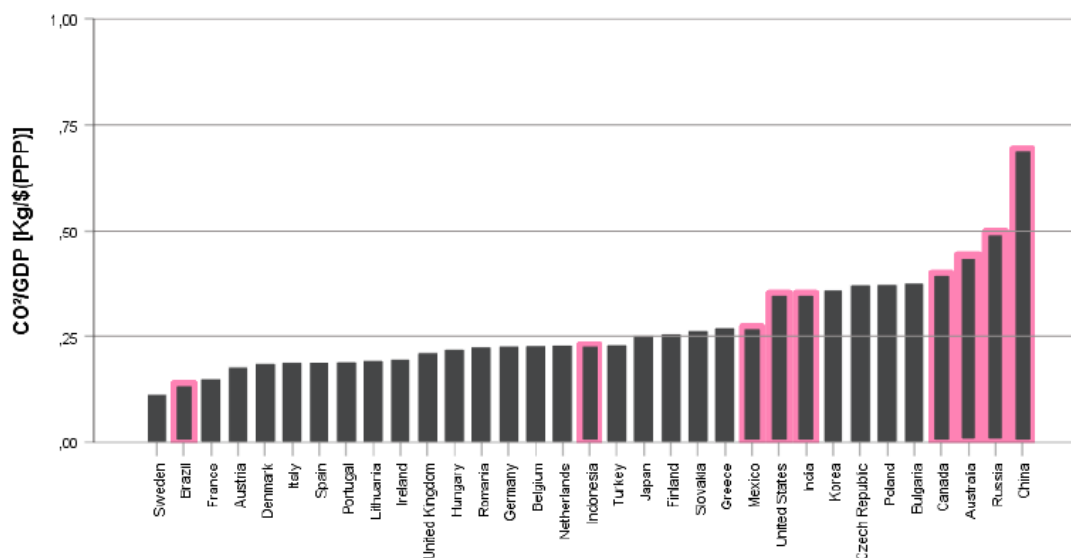


Figure 2.1: National carbon intensities in 2009. Resources-rich countries in pink.

Source: Carbon Dioxide Information Analysis Center.

To illustrate the overall relationship between natural resource abundance and energy intensity, Figure 2.1 ranks countries in our sample by increasing CO<sub>2</sub> intensity (per unit of GDP). The highlighted countries are rich in resources. Among the eleven countries with the highest CO<sub>2</sub> intensity, seven are resource-rich countries (highlighted in pink).<sup>15</sup>

A significant positive relationship can be easily seen in this figure. However, correlation itself is not a causal relationship. Atypical situations emerge, such as resource-poor countries with high CO<sub>2</sub> emissions (Korea, Czech Republic, Poland, Bulgaria), and the case of Brazil, a low emitter, although richly endowed with mineral and fossil resources. The impacts of natural resource abundance on CO<sub>2</sub> intensity remain unclear. The next section will further discuss these issues.

To further investigate what appears in Figure 2.1, we split CO<sub>2</sub> emission levels on the basis of resource-rich and resource-poor countries. Figure 2.2 is somehow surprising and supports our intuition that countries rich in natural resources tend to cause pollution more than resource-poor countries. Since the early 2000s, both groups of countries show two opposite paths for CO<sub>2</sub> emissions. Resource-rich countries are on an increasing trend, while resource-poor countries are cutting or at least stabilizing their CO<sub>2</sub> emissions. This figure suggests that the debate on climate change

15. By restraining our panel to developed countries, we do not consider the OPEC countries which are both very rich in fossil resources and emit high levels of CO<sub>2</sub> (Friedrichs and Inderwildi (2013)). For the clustering between resource-rich and resource-poor countries, see footnote 11.

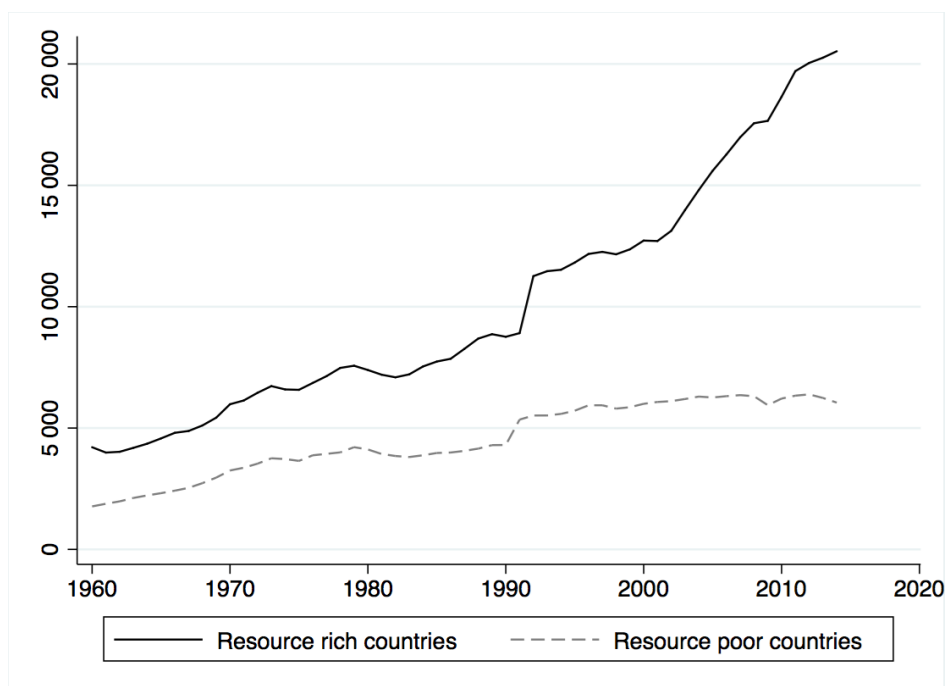


Figure 2.2: CO<sub>2</sub> emissions in OECD countries and BRIC.

Source: Carbon Dioxide Information Analysis Center.

mitigation should rather focus on a comparison of resource-rich countries versus resource-poor countries than the classic developed-country versus developing-country debate.

Like in Friedrichs and Inderwildi (2013), Figure 2.3 plots decarbonation achieved in the observed countries, defined as the reduction in CO<sub>2</sub> intensity over time, against average economic growth rates. Resource-rich countries are represented by circles while resource-poor countries are represented by triangles. Only one country (Indonesia) exhibits an emission intensification during the period; that is, a negative decarbonation (in red, below the horizontal line). The rest of the countries form two groups: above the 45% line, decarbonation is linked to emission reduction (green triangles), while below this line, decarbonation occurs together with emission increase (yellow triangles and circles).

We observe that all resource-rich countries emit more CO<sub>2</sub> despite the decrease in their emission rate, together with some other countries. Only resource-poor developed countries are above the 45% line, which can be interpreted as evidence in favor of a decreasing phase of an EKC. On the contrary, below the 45% line, countries are either still in the ascending phase of a possible EKC (for emerging countries) or never experienced an EKC but witnessed only ever-increasing emissions



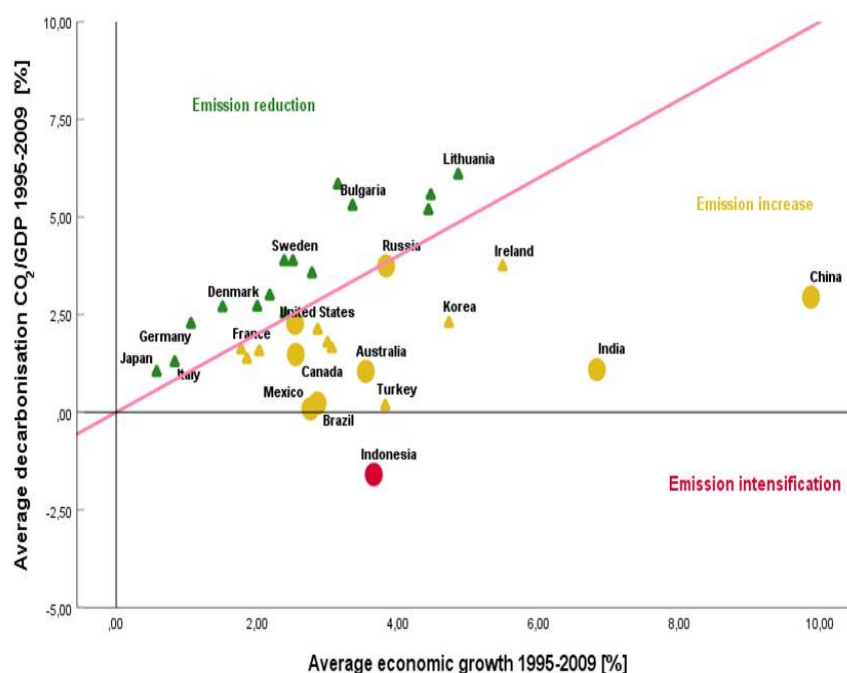


Figure 2.3: Carbon trajectories represented by the average annual increase or decrease in carbon intensity against average economic growth rates between 1995 and 2009.

Source: Carbon Dioxide Information Analysis Center and World Bank national accounts data.

(developed countries like the United States or Australia).

A sectoral presentation of the data is provided in Figures 3.4.a to 3.4.c. The three main sectors presented are mining and utilities, services, and transport and communication. The  $CO_2$  intensity of the sector is represented according to its share in the country's GDP. Large solid black circles are associated with resource-rich countries, while small black circles represent resource-poor countries. With the notations adopted in Equation 2.2, these figures allow to compare the sectoral contributions of sector  $i$  to national carbon intensity across countries, by plotting  $\phi_{ih} \cdot U_{ih} \cdot I_i$  related to  $S_i$ .

Figure 3.4.b is perhaps the most striking: for a given share of the services sector's contribution to the country's GDP, the  $CO_2$  intensity of the sector is highest for resource-rich countries. We observe some evidence of spillover effects. For a given country, a high  $CO_2/VA$  rate in the mining sector (Figure 3.4.a) is also associated with a high ratio in the services sector (Figure 3.4.b).

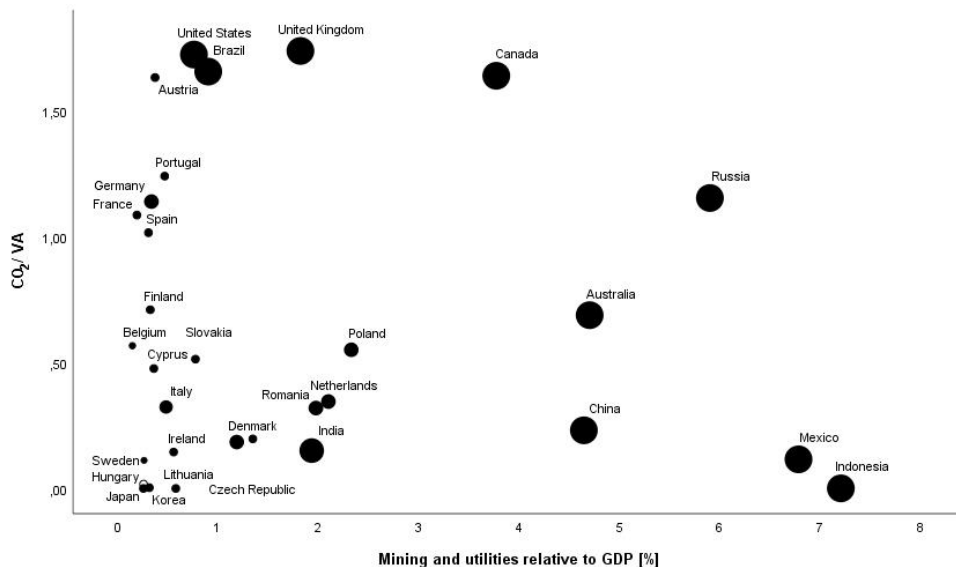


Figure 3.4.a: Sectoral carbon intensity and share of sector (Mining) in the economy. Source: World Input-Output Database.

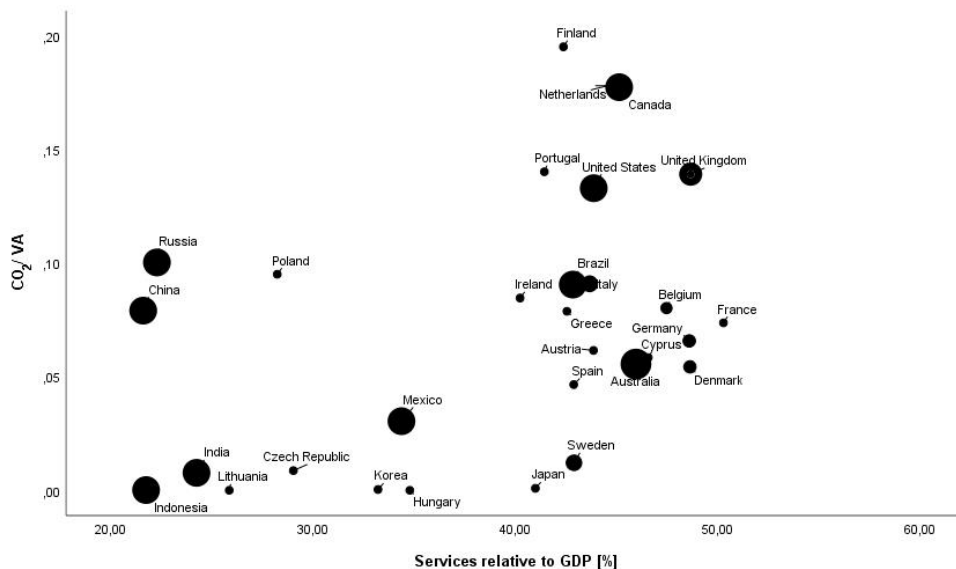


Figure 3.4.b: Sectoral carbon intensity and share of sector (Services) in the economy. Source: World Input-Output Database.

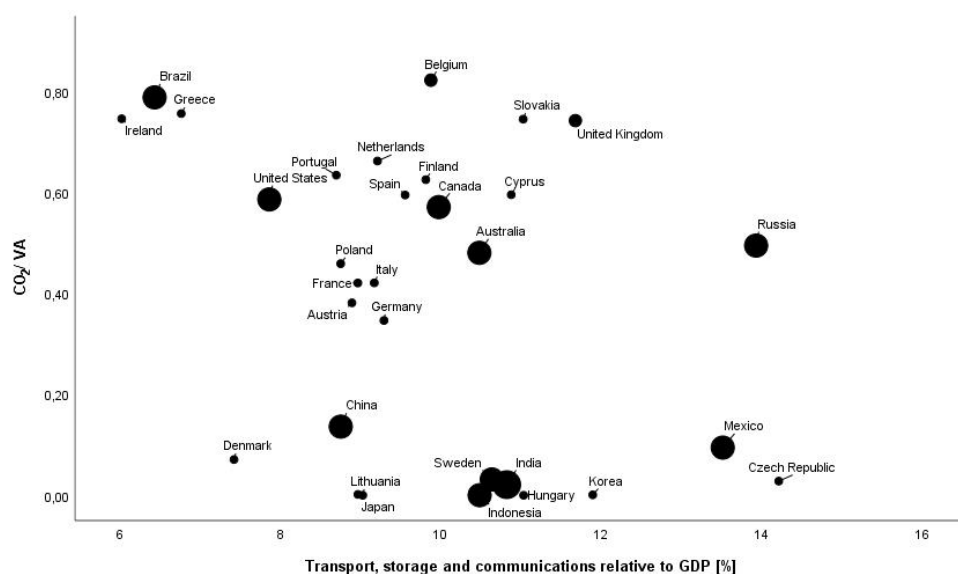


Figure 3.4.c: Sectoral carbon intensity and share of sector (Transports) in the economy. Source: World Input-Output Database.

## 2.4 The empirical model

This section first presents the methodology used for estimates at the national level. We, secondly, present the sectoral approach.

### 2.4.1 Country wide estimation

In this section, we analyze the underlying factors that determine the impact of resource abundance on carbon intensity performance. Resource abundance may directly affect CO<sub>2</sub> emissions; however, the influence may also be indirect, either through the level of corruption or through environmental policy stringency impact. Our empirical approach allows to analyze direct and indirect links. To do so, we estimate the following panel data model:

$$(CO_2/GDP)_{it} = \beta_0 + \beta_1 Abundance_{it} + \beta_2 Abundance_{it}^2 + \beta_3 X_{it} + \alpha_i + \nu_t + \varepsilon_{it} \quad (2.4)$$

$$i = 1, \dots, 29 ; t = 1, \dots, 15,$$

where the variable  $CO_2/GDP$  denotes CO<sub>2</sub> emissions intensity measured as emissions per GDP (kg per PPP \$ of GDP) in country  $i$  at time  $t$ .  $Abundance$  represents natural resources. It tries to capture any potential non-linear effect of natural resources on CO<sub>2</sub> intensity. Thus, we expect

an overall positive effect of abundance, that can be either a quasi-concave function if  $\beta_1 > 0$  and  $\beta_2 \leq 0$ , or a U-shaped curve if  $\beta_1 < 0$  and  $\beta_2 > 0$ .

$X_{it}$  is a set of eleven control variables used in the literature to explain the CO<sub>2</sub> intensity. They can be divided into two different categories. The first set of controls is comprised of preferences and policy measures: environmental policy stringency (EPS), share of alternative and nuclear energy in total energy use, the technological level, law and order index, government stability index, democracy index, population density, urbanisation rate, and the level of corruption. The second set includes climatic variables (heating degree days and cooling degree days). Finally,  $\alpha_i$  is the individual fixed effect that captures the impact of specific unobservable and observable variables that are constant over time for each country. The combination of individual  $\alpha_i$  with time fixed effect  $\nu_t$  avoids any endogeneity issue related to omitted variables. Furthermore, all the variables are in a natural logarithm except corruption, alternative energy use and urbanization rate.

We estimate a panel data model. Ideally, the random effect estimator would be the best choice since it exploits both the cross-section and dynamic dimensions of our panel data in an efficient way (Hill Carter et al. (2012)). However, a robust Hausman test specification rejects it (Wooldridge (2002)). Thus, we use a fixed effect model using the within estimator which is consistent even if the fixed effects are correlated with the independent variables. The within estimator corrects for heteroscedasticity and intragroup correlation. Knowing that CO<sub>2</sub> emissions may be correlated between countries, we rely on two well-known spatial tests: Pesaran parametric test for cross-sectional dependence following the methods shown in Pesaran (2004) and Frees semi-parametric test for cross-sectional dependence using Frees' Q distribution (Frees (1995)). Both tests reject the null hypothesis of cross-sectional independence across panel units. Thus, if we have spatially correlated omitted variables and these omitted variables are independent of the included explanatory variables, then within coefficient estimates are unbiased but inefficient. In this situation, we should allow the error term in the equation to be spatially correlated. To do so, we use a non-parametric technique: Driscoll and Kraay's covariance estimator. Driscoll and Kraay (1998) standard errors are robust to very general forms of cross-sectional "spatial" and temporal dependence when the time dimension becomes large. The results are provided in Section 2.5.

### 2.4.2 Industry specific estimation

Once the concept of a carbon curse has been confirmed at the macroeconomic level, we use sectoral analysis to disentangle the overall effect of resource endowment on CO<sub>2</sub> emissions. We investigate

whether resource-rich countries pollute more than resource-poor countries in all sectors. In other words, are there any spillover effects of carbon-intensive production processes to all sectors of the economy? Obviously, we expect the level of pollution in the mining sector to be higher in resource-rich than in resource-poor countries. However, is it still true for the other sectors? Firstly, we need to distinguish at least two groups of countries: resource-poor and resource-rich countries. To do so, we use the K-means clustering algorithm to find groups which have not been explicitly labeled in the data. The number of clusters to find is explicitly chosen. We set it at two, given the relatively small size of our sample (see subsection 2.3.2).<sup>16</sup> Second, we estimate the following panel data model on each sub-sample and compare the results:

$$(CO_2/VA)_{ijt} = \sum_{j=1}^7 \beta_{1j}(Abundance_{it} * dummy_j) + \beta_2' X_{it} + \beta_3' X_{ijt} + \alpha_i + \delta_j + \theta_{ij} + \delta_{jt} + \nu_t + \varepsilon_{ijt} \quad (2.5)$$

$$i = 1, \dots, 29 ; j = 1, \dots, 7 ; t = 1, \dots, 15.$$

In the above equation,  $(CO_2/VA)_{ijt}$  stands for CO<sub>2</sub> emissions per dollar of value added to sector  $j$  in country  $i$  at time  $t$ , whereas  $X_{it}$  is a vector of  $k$  observed time-varying exogenous characteristics of country  $i$  like the Environmental Policy Stringency Index (EPS), corruption, law and order, urbanisation rate, climatic condition variables (CDD and HDD), and a time fixed effect  $\nu_t$ . We also include  $X_{ijt}$ , a vector of  $k$  observed time-varying exogenous characteristics of sector  $j$  in country  $i$ , like technological level and  $\delta_{jt}$ . All time-invariant characteristics of the countries and industries are captured by the fixed effects which are  $\alpha_i$ ,  $\delta_j$ , and  $\theta_{ij}$ , respectively. Thus, to test if the effect of the resource endowment is different by sector, we introduce an interaction term between natural resources and sectoral dummies variable. Finally, all variables are in a natural logarithm except for corruption. We use the fixed effects estimator and use the same routine as in the country-wide estimation.

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16. Data clustering according to Gan et al. (2007), also known as cluster analysis, is a process of forming groups of objects, or clusters, such that objects in one cluster are very similar and objects in different clusters are dissimilar.

We also use K-Medians clustering which is a variation of K-means clustering where, instead of calculating the mean for each cluster to determine its centroid, one calculates the median. This has the effect of minimizing error over all clusters with respect to the 1-norm distance metric, as opposed to the square of the 2-norm distance metric (which K-means does). In practice, K-means is easily affected by outliers. K-medians is robust to outliers and results in compact clusters.

## 2.5 Estimation results

### 2.5.1 Country wide estimation

Our main model regresses CO<sub>2</sub> intensity on natural resource abundance, incorporating auxiliary variables to assess whether this relationship fits an ever increasing, decreasing, U-shaped or inverted U-shaped pattern. First, we estimate a random model and its results validate the existence of U-shaped behavior. Table 2.4 reports results and several tests: *i*) the F-test for individual effects tests the null of  $\alpha_i = 0, \forall i$  in equation (2.4); *ii*) the Breusch-Pagan test for random effects tests the null of  $Var(\alpha_i) = 0$  in equation (2.4); and *iii*) the Hausman test of fixed effects versus random effects strongly rejects the random effects model. Therefore, to alleviate heterogeneity bias, we rely on a fixed effect model and check for the presence of cross-sectional dependency. Accordingly, we perform various standard tests for cross-sectional dependence proposed by Pesaran (2004) and Frees (1995) and implemented in STATA by De Hoyos and Sarafidis (2006). Test results are reported in Table 2.4 and strongly reject the null hypothesis of cross-sectional independence. Hence, the Driscoll–Kraay estimation is employed, by which the standard error estimates are robust to general forms of cross-sectional and temporal dependence (Hoechle (2007)). Our main interpretations focus only on this estimation strategy.

The results are reported in column (3) of Table 2.4. The estimated coefficients remain unchanged and highly significant when we correct for spatial correlation. On average, all else being equal, a rise of 1% in the share of alternative energy results in 0.14% lower CO<sub>2</sub> intensity. This result indicates that CO<sub>2</sub> emission can be mitigated by increasing renewable energy usage, which is consistent with existing studies (Ben Jebli et al. (2016)). The relationship between Environmental Policy Stringency (EPS) and carbon emissions is negative and significant at the 1% level. Keeping other things constant, a 1% increase in Environmental Policy Stringency decrease CO<sub>2</sub> intensity by 0.06%. This direct effect on CO<sub>2</sub> reflects, for example, the impact of new or stricter command and control instruments. Given that an increase in stringency is generally preceded by a political debate, such an increase may be anticipated in advance. Hence, it is little surprise that the effect can be observed contemporaneously.<sup>17</sup> In addition, the direct effect of technology on CO<sub>2</sub> intensity is significantly positive. Previous contributions have yielded mixed results on the technology/CO<sub>2</sub> relationship (for a summary see Lantz and Feng (2006)). We use a general proxy for technology,

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17. The results indicate that there is no significant change for all variables when using lagged (past) values of the EPS variable. The results for the lagged EPS variable are qualitatively identical and quantitatively similar to those of the benchmark model. Results are available upon request.

Table 2.4: Country wide estimation results – Dependent variable CO<sub>2</sub> per unit of GDP

Model	Random effects		Fixed effects		Fixed effects Driscoll-Kraay estimator	
(CO <sub>2</sub> /GDP)	(1)		(2)		(3)	
Abundance	-0.148**	(-2.63)	-0.085*	(-1.80)	-0.085***	(-3.30)
Abundance <sup>2</sup>	0.003**	(2.44)	0.002*	(1.77)	0.002***	(4.27)
Alternative Energy	-0.137***	(-5.58)	-0.146***	(-7.02)	-0.146***	(-9.75)
Stringency	-0.064**	(-3.83)	-0.060**	(-1.99)	-0.060***	(-2.67)
Heating DD	0.008	(0.40)	0.002	(0.13)	0.002	(0.12)
Cooling DD	0.013	(1.28)	0.017*	(1.76)	0.017*	(1.95)
Technological level	0.064***	(3.83)	0.039*	(1.75)	0.039***	(5.05)
Corruption	0.028	(0.95)	0.032	(1.00)	0.032	(1.49)
Law and Order	-0.078	(-1.50)	-0.094**	(-2.03)	-0.094**	(-2.61)
Institutional quality	-0.082**	(-2.23)	-0.069**	(-2.04)	-0.069***	(-2.75)
Democracy	0.161***	(3.28)	0.149***	(2.82)	0.149***	(6.04)
Urbanisation rate	0.003	(0.66)	0.007	(1.31)	0.007**	(2.31)
Population density	0.013	(0.25)	0.724**	(2.34)	0.724***	(5.50)
Constant	-0.358	(-0.46)	-4.219**	(-2.59)	-4.22***	(-5.51)
Observations	396		396		396	
Number of countries	29		29		29	
	F-test for individual effects					
F(28,340)	267.34 [0.000]					
	Breusch Pagan test for random effects					
$\chi^2_{(1)}$	1291.07 [0.000]					
	Hausman test of fixed effects versus random effects					
$\chi^2_{(18)}$	669.482 [0.000]					
	Pesaran's test of cross sectional independence					
	-2.131 [0.0011]					
	Frees' test of cross sectional independence					
	4.983 [0.000]					

Note: Standard errors are in (); \*, \*\* and \*\*\* refer to the 10%, 5% and 1% significance levels, respectively; P-values are in [ ].

and we do not specifically consider green technologies. Qualitative results on technology can be explained by the fact that new technologies are not necessarily less emitting than older technologies. Therefore, new technologies are not less emitting than older ones, which may explain the positive impact of technological development on CO<sub>2</sub> intensity. In line with earlier studies, urbanization impacts positively CO<sub>2</sub> emissions. An increase by 1 percentage-point in urbanization increases CO<sub>2</sub> intensity by 0.007%, all things being equal. The reasons are threefold: i) urbanization is driving up energy consumption as a result of widespread improvements in the quality of life and increase in the demand for goods and services ; ii) the shift from traditional fuels (straw, wood) to more carbon-intensive fossil fuels ; and iii) the increasing number of small households (Krey et al., 2012). Population density is positively associated with CO<sub>2</sub> intensity. A 1% increase in population-density results, all things being equal, in a 0.72% increase in CO<sub>2</sub> intensity. This latter result is consistent with those of Shahbaz et al. (2015) for the Australian case and Zhu and Peng (2012) for the Chinese one, who find the elasticity of carbon emissions with respect to population size to be positive. The estimated coefficients on climatic variables (CDD and HDD) show no impact on CO<sub>2</sub> intensity. This result can be explained by the fact that we consider average annual temperatures, which leads to insignificant results. Corruption has no significant impact on our results. This may be due to the developed countries that are in our sample. Indeed, a survey by the Organization for Economic Cooperation and Development (OECD) indicated that corruption was a common issue in both developed and developing countries, and, comparatively, it had greater effect on CO<sub>2</sub> emissions in developing countries than that in developed countries.<sup>18</sup> For the governance indices, we show negative impacts of the law and order variable and the government stability on CO<sub>2</sub> intensity. Indeed, more secure property rights are associated with better execution of contracts and effective environmental regulations. Political stability has a positive effect on the enforcement of government regulations. Indeed, high turnover of politicians limits their ability to take effective commitments against polluting firms (Fredriksson and Svensson, 2003). These results provide support that good governance matters in terms of CO<sub>2</sub> emissions control. The sign of the estimated parameter associated with democracy is positive and significantly different from zero. This is a more striking result as it means that a country that improves its political freedoms will emit more CO<sub>2</sub> per unit of GDP. We are however aware of studies concluding to a negative impact of democracy on CO<sub>2</sub> emissions, especially when governments react to the increased possibility for people to express their preferences for environmental quality (Farzin and Bond, 2006). Our result may be explained by the fact that democracy leads to great political freedom allowing

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18. [http://www.oecd.org/daf/anti-bribery/ConvCombatBribery\\_ENG.pdf](http://www.oecd.org/daf/anti-bribery/ConvCombatBribery_ENG.pdf)



individuals and organizations to form lobby or political groups (Torras and Boyce, 1998) which are then able to influence government's decisions in favor of more polluting activities. Greater political freedom also gives citizens and firms the potential to fully exploit their productive and consumption abilities. These latter will result in an increase in CO<sub>2</sub> emissions when they are not sufficiently offset by environmental regulation. We conclude that the relationship between democracy and carbon intensity is driven by two competing mechanisms. This duality becomes obvious when we look at the level of fossil fuel subsidies. In the case of the United States, where democracy has a very high score, one may expect a big fight against climate change. However, this seems to be a red herring because the level of subsidies for fossil fuels in 2015 reached \$649 billion, ranking the USA at the second place worldwide just after China with \$1.4 trillion (Coady et al., 2017). We are tempted to think that the United States is an exception among democratic countries. However, the European Union, although considered as a pioneer and a leader in the fight against climate change, was ranked 4th worldwide in fossil-fuel subsidies in 2015 with \$289 billion just ahead of India with \$209 billion (Coady et al., 2017). Despite the implementation of climate change policy instruments in democratic countries, the level of subsidies for fossil-fuels is so high that it may reduce or even counteract the positive impacts of those environmental policies. A reform of subsidies in these countries, i.e. the implementation of energy prices that internalize environmental costs, would be a significant progress toward climate change mitigation. According to Coady et al. (2017), cutting fossil-fuel subsidies would reduce global carbon emissions by 21% and deaths from air pollution by 55%. This will also increase revenues by 4% of world GDP and social welfare by 2.2% of world GDP. These elements may help to better understand the duality in the relationship involving the level of democracy and CO<sub>2</sub> emissions.

Finally, we find that the linear and squared terms of natural resource abundance have a negative and positive effect on CO<sub>2</sub> intensity at the 1% significance levels, respectively. It clearly shows the existence of a U-shaped relationship between natural resource abundance and CO<sub>2</sub> intensity. In other words, there is a turning point in the relationship between CO<sub>2</sub> per unit of GDP and resource abundance (both expressed in natural logarithms), such that, before this point, the elasticity is negative, while it is positive beyond.

Therefore, we find a decreasing relationship between CO<sub>2</sub> and abundance for relatively resource-poor countries (before the turning point). Counterintuitively, this means that more resources reduce CO<sub>2</sub> intensity in those countries (Balsalobre-Lorente et al. (2018)). This result reflects the complex nature of the determinants of CO<sub>2</sub> emissions: the characteristics of the energy-mix ( $U_{ih}$ ) and the sectoral structure of the economy ( $S_i$ ) are essential elements for some resource-poor countries. Thus,

when comparing two resource-poor countries, one country may have more resources while emitting less CO<sub>2</sub> if the difference in abundance is due to less emitting resources (gas compared to coal, for example); the energy mix will probably be less polluting. For the same reasons (the change in the energy mix), the discovery of resources (shale gas, shale oil, or minerals) will not necessarily lead to an increase in emissions or even, increasing resources could be beneficial in terms of CO<sub>2</sub> emissions per unit of GDP.<sup>19</sup> In this case, the intuition of the mechanisms could be as follows. Resource-poor countries have little crowding out effect (low entry barrier for renewable energies for instance), and the diffusion of polluting practices to non-fossil sectors is still low. An increase in resources should not imply a structural change in production; CO<sub>2</sub> should remain constant while the production may increase significantly. The induced economic growth may accelerate investment in research and development, which contributes to improved energy efficiency and reduced carbon intensity. Moreover, for a given level of resources, a country with a larger service sector will emit less CO<sub>2</sub>. These mechanisms (energy substitution in the energy mix and sectoral structure of the economy) are crucial in resource-poor countries, which confirms that these countries are not too dependent on their resources.

For resource-rich countries, we find a carbon curse: any increase in resources translates into an increase in carbon intensity. The scale effect, therefore, plays a major role, in addition to the likely rigidity of technologies and the sectoral structure of the economy, which can be explained by the country's dependence on its natural resources. Actually, resource-rich countries have developed specific industrial structures which are largely influenced by the natural resource endowment. Indeed, the abundance of natural resources leads to low prices of resources, which leads to high extensive and inefficient energy consumption patterns and low emissions efficiency (Adom and Adams (2018); Yang et al. (2018)). The role of the sectoral structure in CO<sub>2</sub> emissions is examined in the next section.

Our main conclusion is that the relationship between resources and carbon intensity is not monotonous. This relationship is decreasing for resource-poor countries, increasing for resource-rich countries, and ambiguous for intermediate countries. The carbon curse is, therefore, a somewhat more complex phenomenon than Friedrichs and Inderwildi (2013) suggest and does not affect all countries equally, specifically, those with few resources. Our study confirms that for a resource-rich country, it is difficult to avoid the carbon curse, perhaps even more difficult than avoiding the resource curse, in general. While one of the standard causes of the resource curse is the low quality of the

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19. Balsalobre-Lorente et al. (2018) obtain similar results for 5 European resource-poor countries (France, Germany, Italy, Spain, and the United Kingdom).

institutions or the level of corruption, the carbon curse is clear for the resource-rich countries in our sample; corruption does not play any significant role in our result. Indeed, our sample confirms the existence of a carbon curse even though it does not include countries facing the resource curse.

### 2.5.2 Industry country specific estimation

To further investigate the complexity of the carbon curse highlighted at the national level, we rely on a country-sectoral analysis. This multilevel analysis provides economy and sector-specific coefficients for variables of interest, which forms the basis of a more detailed study on the heterogeneous effects of natural resource abundance on sectoral energy intensity. To do this, we group the countries according to their level of abundance using the K-means method. The two groups obtained are as follows:

- resource-rich countries: Russia, China, United States, Canada, Australia, India, Brazil, and Indonesia.
- resource-poor countries: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Netherlands, Poland, Portugal, Slovakia, Spain, Sweden, Turkey, and the United Kingdom.<sup>20</sup>

The results are shown in Table 2.5.<sup>21</sup>

The results show the heterogeneous impacts of natural resources endowment on sectoral energy intensity across sectors but also across the two groups of countries. For resource-rich countries, the positive relationship between natural resources and sectoral energy intensity can be clearly seen except in the agricultural and construction sector. As expected, the highest elasticity comes from the mining sector. On average, a 1% increase in natural resources endowment leads to a 0.84% increase in mining sectoral energy intensity. When it comes to the heterogeneous effects across service and non-service sectors (elasticities of transport (0.49), electricity (0.42), manufacturing

20. Both methods (K-means and K-medians) give the same groups of countries except for the United Kingdom that becomes a resource-rich country with K-medians method. However, the overall results do not change even when the United Kingdom is considered as included in the natural resource-rich category.

21. All the variables in Table 2.5 that end with “\_abund” correspond to the dummy variable ( $Abundance_{it\_dummy_j}$ ) in equation (2.5). The related estimated coefficient captures the average impact of abundance on CO<sub>2</sub> sectoral intensity across sectors.

Table 2.5: Industry country estimation results – Dependent variable CO<sub>2</sub> per unit of value added

(CO <sub>2</sub> /VA)	Fixed effects			
	Resource-rich		Resource-poor	
Agriculture_abund	0.097	(1.23)	-0.058**	(-2.51)
Transport_abund	0.493***	(3.44)	-0.0935***	(-4.12)
Manufacturing_abund	0.497***	(5.25)	-0.051***	(-3.48)
Construction_abund	-0.24	(-1.58)	0.054**	(2.61)
Electricity_abund	0.421***	(2.80)	0.081***	(3.12)
Mining_abund	0.846***	(5.10)	0.069	(1.05)
Service_abund	0.548***	(4.72)	0.011	(0.71)
Stringency	-0.007**	(-2.41)	-0.009	(-0.35)
Technological level	-0.051**	(-2.11)	-0.011	(-0.42)
urbanisation rate	0.007*	(-1.84)	0.006	(2.10)
Law and Order	-0.097	(-5.13)	0.007	(0.81)
Heating DD	-0.020	(-0.76)	0.401***	(3.70)
Cooling DD	0.125	(1.66)	0.013	(0.78)
Constant	-13.30***	(-8.15)	-5.87***	(-5.19)
Observations	805		1960	
Number of countries	8		20	

Note: Standard errors are in (); \*, \*\* and \*\*\* refer to the 10%, 5% and 1% significance levels, respectively.

(0.49), and services (0.54)), we find that the impacts of natural resource abundance in increasing sectoral energy intensity are quite similar between the services and non-services sectors. This was less expected. Spillover effects of the influence of abundance are, thus, occurring towards less resource-intensive sectors. Indeed, depending on resource advantages, resource-based countries have developed compatible industrial structures (Shi (2013)). Most of the industries in these countries are likely to be characterized by high energy and emissions intensities. The abundance of natural resources leads to low prices of resources. This has led to high extensive and inefficient energy consumption patterns and low emissions efficiency (Adom and Adams (2018); Yang et al., 2018) because of lower willingness to invest in resource-saving technologies and equipment (Shi (2014)). In addition, non-resource-intensive sectors are closely attached to the resource-intensive ones, and, as a result, it may lead to resource dependence, which worsens the carbon emissions efficiency in non-resource-intensive sectors (like services). Overall, the extensive use of resources will inevitably lead to a decline in carbon emissions efficiency because companies' behavior in resource-based countries is different from those in other regions. Finally, the Environmental Policy Stringency significantly reduces CO<sub>2</sub> intensity in resource-rich countries.

For resource-poor countries, the empirical findings show opposite results which confirms the heterogeneous impact of natural resource abundance across the two groups of countries. The relationship

between natural resources and sectoral energy intensity is mixed. On average, a 1% increase in natural resources endowment leads to a 0.08% increase in electricity sectoral energy intensity which is five times smaller than for resource-rich countries. Interestingly, there is a clear negative relationship between natural resources and CO<sub>2</sub> intensity of manufacturing, transport, and the agriculture sector. It can be caused by changes in energy efficiency in these sectors prompted by the rapid increases in energy prices between 2002 and 2009. Domestic policies may respond to the distortions due to energy price fluctuations; for example, energy price reforms (Feng et al. (2009); Yang et al. (2016); Zhao et al. (2010)), tax policies on energy-intensive products and sectors (Price et al. (2011)), and public funding and programs towards changing consumer behaviors regarding energy use (Allcott and Mullainathan (2010)). Climatic conditions during heating days may increase carbon intensity in all sectors for resource-poor countries.

## 2.6 Discussion

In this section, we carry out several robustness checks, for which all results are shown in Appendix.

First, our estimated model relates the carbon intensity of GDP to abundance. Since the most emitting and resource-rich countries are also the largest countries of our sample, one could worry about the potential influence of population on our results. This is the reason why we also estimated the impact of abundance on emissions per capita, introducing GDP per capita as an additional explanatory variable in this case. Results are provided in Table 2.7: the U-shaped curve is unaffected. The other coefficients change slightly, keeping the same conclusions qualitatively except for the law and order, which is no longer significant.

Second, Table 2.2 and Figure 2.1 show that Brazil, Russia, India, and China (the BRIC) are among the most resource-rich countries and are also the largest emitters (except Brazil). We, therefore, exclude these countries from our sample and estimate the model only for OECD countries. The results are clearly not qualitatively affected except for the democracy variable which is no longer significant. This result show that when excluding countries that are far from the ideal democracy, the positive impact vanishes. Also, the estimated coefficients for *Abundance* and *Abundance*<sup>2</sup> are both lower than that for the whole sample (Table 2.8). However, considering only long-established industrialized countries, we still obtain a U-shaped curve between carbon intensity and natural resource abundance. This U-shaped curve is only a little flatter than when BRIC countries are included.

Third, to assess whether some kinds of natural resources drive the results, we estimate the same relationship for each kind of natural resource taken separately: fossil fuels and mineral resources (Table 2.10); coal, oil, or natural gas (Table 2.9). Intuitively, mineral resource abundance does not significantly impact carbon intensity of GDP. The relationship is ever increasing in the case for coal, while the U-shaped curve is clearly visible for oil and natural gas. A country could have large coal reserves but not exploit them, and could use nuclear plants to produce electricity. In this case, any increase in coal abundance would not affect CO<sub>2</sub> emissions.

Fourth, we extend the model by introducing GDP per capita as an explanatory variable. We also test for the significance of a cubic functional form specification of the relationship between CO<sub>2</sub> intensity and resource abundance. Table 2.11 reports the corresponding estimation results. We find a negative and significant impact of GDP per capita on CO<sub>2</sub> intensity and our main results remain qualitatively unchanged. The three estimated parameters associated with the resource abundance variables entering the cubic functional form are all insignificant. We then reject the cubic functional form in favor of squared relationship between resource abundance and CO<sub>2</sub> intensity.

Fifthly, we check whether the results obtained at the macroeconomic level over the restricted period compatible with sectoral data availability still hold over the extended period of 1995–2014. As shown in Table 2.12, the U-shaped curve still appears.

To sum up, the carbon curse is a new theory related to the resource curse but is quite distinct from the latter. To our best knowledge, this article is the first to test whether the carbon curse hypothesis holds. We find a strong evidence of carbon curse in developed countries. However, our sample includes countries with different industrial structures and trajectories as they are at different stage of development (Rodrik, 2016). To tackle this limit, we estimate our model on a subsample of OECD countries and check for the robustness of our results. We can reasonably assume that the OECD countries (early boomers) have reached their steady states while the BRIC countries (late boomers) are still in their transition phase toward their steady states (Guilló and Perez-Sebastian, 2015).<sup>22</sup> The assumption of homogeneity of OECD countries is reinforced by the convergence of CO<sub>2</sub> emissions in those countries (Brock and Taylor, 2010; Jobert et al., 2010). However, even with the OECD sample, there are still disparities regarding initial conditions. We are aware that fully controlling for initial conditions needs more than running regressions on subsample of homogeneous countries. We consequently go further and consider the urbanization rate variable to proxy for structural change.

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22. Examples of early-bloomers include high income nations such as the U.S., the European Union countries, or Japan. Late-bloomers are Brazil, Russia, India and China.

The date of natural resources discoveries play an important role in the CO<sub>2</sub> trajectory of different countries. Unfortunately, this is not addressed in this article due to limited data availability. The available database needs to be extended to countries' early stages of development and early resource discoveries in order to better control for initial conditions and assess their major role in CO<sub>2</sub> intensity trajectories. Lastly, despite our useful decomposition analysis, the carbon curse theory needs definitely a theoretical model that will combine carbon emissions and structural transformation dimensions (at a country and multi-sectoral level?). A starting point for future researches may be the model of Guilló and Perez-Sebastian (2015).

## 2.7 Conclusion

In this study, we empirically assess the carbon curse assumption. We demonstrate that the relationship between CO<sub>2</sub> emissions per unit of GDP and abundance in natural resources is U-shaped. The carbon curse appears only after the turning point, beyond which countries rich in coal, oil, gas, and minerals emit more CO<sub>2</sub> per unit of GDP compared with countries where natural resources are relatively rare. The carbon curse is, therefore, a somewhat more complex phenomenon, for which the nature of resources owned and spillover effects in the whole economy play a crucial role. We then test the consequences of abundance on the sectoral emissions for two groups of countries, depending on their resource endowments. We confirm that a country rich in fossil and mineral resources pollutes more in resource-related sectors. We also find that CO<sub>2</sub> intensity is positively and highly impacted in all other sectors, even in the services sector. That is explained not only by a composition effect (characterized by a predominance of the mining sector in the GDP) but also by spillover effects (due to a weak environmental policy) and, potentially, a crowding out effect (likely induced by barriers to the development of renewable energies, imposed by the fossil energy sectors). Further research may address the potential links between these pollution mechanisms and the characteristics of the resources (natural gas, non-conventional oil, coal, and mineral resources, among others).

These results suggest that resource abundance should be a key variable in climate policy negotiations. Taking it into account would make it possible to target the main countries to be regulated better. Indeed, rather than focusing on a debate on the efforts to be made, which pits developed countries against developing countries, it would be more appropriate to group and coordinate the countries according to their natural resources endowment.

## 2.8 Appendix

Table 2.6: Explanatory variables –details and sources

Variable	Units of measurement	Source
CO <sub>2</sub> emissions macro et micro (in logarithm)	carbon dioxide (CO <sub>2</sub> ) emission in kilograms per US\$ of GDP (2011 Purchasing Parity Power)	<a href="http://databank.worldbank.org/">http://databank.worldbank.org/</a>
Resource abundance (in logarithm)	2005 US\$	<a href="http://databank.worldbank.org/">http://databank.worldbank.org/</a>
Heating degree days (HDD) Cooling degree day (CDD) (in logarithm)	Temperature reference: 18°C and frequency of 6hrs	<a href="https://www.kapsarc.org/">https://www.kapsarc.org/</a>
Environmental Policy Stringency index (EPS) (in logarithm)	OECD Environmental Policy Stringency Index: from 0 (not stringent) to 6 (highest degree of stringency)	<a href="https://stats.oecd.org/">https://stats.oecd.org/</a> DataSetCode=EPS
Technology level (in logarithm)	Macro level: number of filed patents in a national patent authority from World Intellectual Property Organization (WIPO)	<a href="http://databank.worldbank.org/">http://databank.worldbank.org/</a>
	Sector level: high-skilled working hours divided by total working hours	<a href="http://www.wiod.org/">http://www.wiod.org/</a>
Alternative energy use	Renewable and nuclear energy (% of total energy use)	<a href="http://databank.worldbank.org/">http://databank.worldbank.org/</a>
Corruption	Index of governance performance: from -2.5 (weak) to 2.5 (strong)	Kaufman et al. (2010)
Law and Order (in logarithm)	Index of governance performance: from 0 (weak) to 6 (strong)	<a href="https://www.prsgroup.com/">https://www.prsgroup.com/</a>
Government Stability (in logarithm)	Index of governance performance: from 0 (weak) to 12 (strong)	<a href="https://www.prsgroup.com/">https://www.prsgroup.com/</a>
Democracy (in logarithm)	Index of governance performance: from 0 (Autarchies) to 6 (Alternating Democracies)	<a href="https://www.prsgroup.com/">https://www.prsgroup.com/</a>
Urbanisation rate	People living in urban areas (% of total population)	<a href="http://databank.worldbank.org/">http://databank.worldbank.org/</a>
Population density (in logarithm)	Population divided by land area in square kilometers	<a href="http://databank.worldbank.org/">http://databank.worldbank.org/</a>
GDP per capita (in logarithm)	2011 Purchasing Parity Power (PPP)	<a href="http://databank.worldbank.org/">http://databank.worldbank.org/</a>



Table 2.7: Country wide estimation – Dependent variable CO<sub>2</sub> per capita

Model	Random effects		Fixed effects		Fixed effects Driscoll-Kraay estimator	
(CO <sub>2</sub> /POP)	(1)		(2)		(3)	
Abundance	-0.147***	(-2.80)	-0.109**	(-2.04)	-0.109**	(-3.00)
Abundance <sup>2</sup>	0.003**	(2.47)	0.002**	(1.96)	0.002***	(2.89)
GDP_capita(PPP)	0.591***	(8.63)	0.540***	(7.48)	0.540***	(7.22)
Alternative Energy	-0.134***	(-5.28)	-0.140***	(-6.95)	-0.140***	(-11.06)
Stringency	-0.035*	(-1.69)	-0.035*	(-1.65)	-0.035**	(-2.06)
Heating DD	0.015	(0.72)	0.005	(0.28)	0.005	(0.19)
Cooling DD	0.009	(0.75)	0.017	(1.47)	0.017**	(2.30)
Technological level	0.103***	(4.82)	0.091***	(3.80)	0.091***	(6.81)
Corruption	0.042	(1.45)	0.034	(1.48)	0.034	(1.52)
Law and Order	0.004	(0.12)	-0.019	(-0.59)	-0.019	(-0.85)
Institutional quality	-0.030	(-1.04)	-0.022**	(-0.91)	-0.022***	(-1.15)
Democracy	0.133***	(3.13)	0.117**	(2.50)	0.117***	(3.62)
Urbanisation rate	0.007**	(1.99)	0.008*	(1.77)	0.008***	(2.83)
Population density	-0.017	(-0.33)	0.547***	(2.92)	0.547***	(4.33)
Constant	-3.93***	(-4.76)	-6.838***	(-6.12)	-6.838***	(-8.46)
Observations	396		396		396	
Number of countries	29		29		29	
F-test for individual effects						
F(28,339)	335.77 [0.000]					
Breusch Pagan test for random effects						
$\chi^2_{(1)}$	1288.90 [0.000]					
Hausman test of fixed effects versus random effects						
$\chi^2_{(15)}$	129.616 [0.000]					
Pesaran's test of cross sectional independence						
-2.059 [0.0396]						
Frees' test of cross sectional independence						
4.223[0.000]						

Note: Standard errors are in (); \*, \*\* and \*\*\* refer to the 10%, 5% and 1% significance levels, respectively; P-values are in [ ].

Table 2.8: Country wide estimation – OECD Countries only

Model	Random effects		Fixed effects		Fixed effects Driscoll-Kraay estimator	
(CO <sub>2</sub> /GDP)	(1)		(2)		(3)	
Abundance	-0.144**	(-2.40)	-0.120**	(-2.35)	-0.120***	(-5.71)
Abundance <sup>2</sup>	0.003**	(2.09)	0.003**	(2.08)	0.003***	(5.24)
Alternative Energy	-0.140***	(-6.46)	-0.145***	(-7.60)	-0.145***	(-15.02)
Stringency	-0.061**	(-2.23)	-0.066**	(-2.57)	-0.066***	(-6.06)
Heating DD	0.352***	(4.18)	0.357***	(5.90)	0.357***	(11.40)
Cooling DD	0.029***	(3.70)	0.030***	(3.87)	0.030***	(3.80)
Technological level	0.079***	(4.59)	0.074***	(4.04)	0.074***	(7.14)
Corruption	0.021	(0.69)	0.022	(0.75)	0.022	(1.33)
Law and Order	-0.015	(-0.25)	-0.056	(-0.92)	-0.056*	(-1.68)
Institutional quality	-0.031	(-0.95)	-0.033	(-1.11)	-0.033***	(-4.71)
Democracy	-0.043	(-0.78)	-0.044	(-0.87)	-0.044	(-1.07)
Urbanisation rate	0.004**	(1.22)	0.006	(1.23)	0.006***	(3.10)
Population density	-0.014	(-0.26)	0.59*	(1.79)	0.592***	(4.52)
Constant	-3.56***	(-2.70)	-6.65***	(-3.68)	-6.65***	(-12.97)
Observations	326		326		326	
Number of countries	24		24		24	
F-test for individual effects						
F(23,275)	244.15 [0.000]					
Breusch Pagan test for random effects						
$\chi^2_{(1)}$	1048.20 [0.000]					
Hausman test of fixed effects versus random effects						
$\chi^2_{(16)}$	243.399 [0.000]					
Pesaran's test of cross sectional independence						
	-2.220 [0.026]					
Frees' test of cross sectional independence						
	3.537 [0.000]					

Note: Standard errors are in (); \*, \*\* and \*\*\* refer to the 10%, 5% and 1% significance levels, respectively.

Table 2.9: Country wide estimation – Type of fossil resources

Model (CO <sub>2</sub> /GDP)	Coal		Oil		Natural Gas	
	Driscoll-Kraay estimator		Driscoll-Kraay estimator		Driscoll-Kraay estimator	
	(1)	(2)	(3)	(4)	(5)	(6)
Abundance	-0.005	(-1.27)	-0.010**	(-2.22)	-0.008**	(-2.01)
Abundance <sup>2</sup>	0.0001*	(1.68)	0.001***	(3.21)	0.0009**	(2.38)
Alternative Energy	-0.147***	(-12.69)	-0.150***	(-8.55)	-0.145***	(-9.85)
Stringency	-0.067***	(-3.20)	-0.067***	(-2.84)	-0.064***	(-2.90)
Heating DD	0.001	(0.08)	0.002	(0.01)	0.001	(0.08)
Cooling DD	0.018**	(2.37)	0.018*	(1.80)	0.018**	(2.76)
Technological level	0.044***	(6.46)	0.040***	(4.82)	0.039***	(6.05)
Corruption	0.026	(1.35)	0.026	(1.14)	0.024*	(1.72)
Law and Order	-0.085**	(-2.26)	-0.089**	(-2.33)	-0.088**	(-2.74)
Institutional quality	-0.069**	(-2.47)	-0.065**	(-2.52)	-0.065***	(-2.53)
Democracy	0.156***	(6.41)	0.153***	(5.65)	0.154***	(7.92)
Urbanisation rate	0.007**	(2.35)	0.008**	(2.35)	0.007***	(2.77)
Population density	0.751***	(6.59)	0.727***	(5.47)	0.739***	(6.74)
Constant	-5.42***	(-10.63)	-5.42***	(-8.25)	-5.39***	(-10.30)
Observations	396		396		396	
Number of countries	29		29		29	

Note: Standard errors are in (); \*, \*\* and \*\*\* refer to the 10%, 5% and 1% significance levels, respectively.

Table 2.10: Country wide estimation – Fossil vs mineral resources

Model (CO <sub>2</sub> /GDP)	Fossil Fuels		Minerals	
	Driscoll-Kraay estimator		Driscoll-Kraay estimator	
	(1)		(2)	
Abundance	-0.021***	(-3.49)	-0.004	(-1.25)
Abundance <sup>2</sup>	0.0012***	(3.73)	0.0002	(1.10)
Alternative Energy	-0.145***	(-6.75)	-0.147***	(-6.18)
Stringency	-0.066***	(-3.07)	-0.064***	(-2.47)
Heating DD	0.0004	(0.02)	0.001	(0.06)
Cooling DD	0.017	(1.14)	0.018	(1.09)
Technological level	0.034***	(3.38)	0.041***	(2.85)
Corruption	0.036	(1.19)	0.024	(0.91)
Law and Order	-0.120**	(-2.36)	-0.089**	(-2.18)
Institutional quality	-0.063**	(-1.99)	-0.068**	(-2.02)
Democracy	0.142***	(4.68)	0.156***	(5.97)
Urbanisation rate	0.007**	(2.23)	0.007**	(1.98)
Population density	0.821***	(5.38)	0.746***	(4.26)
Constant	-5.81***	(-7.81)	-5.40***	(-6.14)
Observations	496		496	
Number of countries	29		29	

Note: Standard errors are in ( ) ; \*, \*\* and \*\*\* refer to the 10%, 5% and 1% significance levels, respectively.

Table 2.11: Country wide estimation – Flexible functional forms

Model (CO <sub>2</sub> /GDP)	Quadratic		Cubic	
	Driscoll-Kraay estimator		Driscoll-Kraay estimator	
	(1)		(2)	
Abundance	-0.109***	(-3.00)	-0.270	(-0.91)
Abundance <sup>2</sup>	0.002***	(2.89)	0.01	(0.63)
Abundance <sup>3</sup>			-0.0001	(-0.36)
GDP per capita	-0.382***	(-8.09)	-0.380***	(-8.19)
Alternative Energy	-0.140***	(-11.06)	-0.140***	(-10.46)
Stringency	-0.035**	(-2.06)	-0.035**	(-2.11)
Heating DD	0.005	(0.19)	0.004	(0.18)
Cooling DD	0.017**	(2.30)	0.017**	(2.35)
Technological level	0.091***	(6.81)	0.091***	(6.69)
Corruption	0.034	(1.45)	0.033	(1.11)
Law and Order	-0.019	(-0.78)	-0.021	(-0.77)
Institutional quality	-0.069	(-1.04)	-0.022	(-1.16)
Democracy	0.115***	(3.20)	0.115***	(3.15)
Urbanisation rate	0.008***	(3.04)	0.008***	(3.05)
Population density	0.551***	(4.17)	0.560***	(3.63)
Constant	0.03	(0.04)	0.62	(0.45)
Observations		496		496
Number of countries		29		29

Note: Standard errors are in (); \*, \*\* and \*\*\* refer to the 10%, 5% and 1% significance levels, respectively.

Table 2.12: Country wide estimation results over the 1995–2014 period

Model	Random effects		Fixed effects		Fixed effects Driscoll-Kraay estimator	
(CO <sub>2</sub> /GDP)	(1)		(2)		(3)	
Abundance	-0.129*	(-1.93)	-0.041	(-0.83)	-0.041**	(-2.36)
Abundance <sup>2</sup>	0.003**	(2.09)	0.001	(0.79)	0.001**	(2.11)
Alternative Energy	-0.144***	(-6.62)	-0.146***	(-7.74)	-0.146***	(-10.22)
Stringency	-0.062**	(-2.28)	-0.073***	(-3.17)	-0.073***	(-3.01)
Heating DD	-0.013	(-0.61)	-0.021	(-0.98)	-0.021	(-0.84)
Cooling DD	-0.003	(0.28)	-0.023**	(2.04)	-0.023***	(3.53)
Technological level	0.056***	(3.32)	0.030*	(1.70)	0.030***	(6.10)
Corruption	--0.033	(-0.76)	0.010	(0.28)	0.010	(0.76)
Law and Order	0.0005	(0.01)	-0.036	(-0.64)	-0.036	(-1.18)
Institutional quality	-0.071**	(-2.09)	-0.052	(-1.58)	-0.052**	(-2.35)
Democracy	0.123**	(2.07)	0.102*	(1.84)	0.102***	(4.59)
Urbanisation rate	0.007	(1.34)	0.009**	(1.98)	0.009***	(4.60)
Population density	0.054	(0.92)	1.026***	(4.56)	1.026***	(12.84)
Constant	-0.67	(-0.91)	-5.36***	(-4.83)	-5.36***	(-17.34)
Observations	514		514		514	
Number of countries	29		29		29	
F-test for individual effects						
F(28,464)	253.41 [0.000]					
Breusch Pagan test for random effects						
$\chi^2_{(1)}$	3449.77 [0.000]					
Hausman test of fixed effects versus random effects						
$\chi^2_{(14)}$	185.719 [0.000]					
Pesaran's test of cross sectional independence						
	-2.537 [0.0112]					
Frees' test of cross sectional independence						
	6.303 [0.000]					

Note: Standard errors are in ( ) ; \*, \*\* and \*\*\* refer to the 10%, 5% and 1% significance levels, respectively.



## Chapter 3

# Revisiting the resource curse: does volatility matters?

YASSINE KIRAT<sup>1</sup>

### 3.1 Introduction

According to the resource curse paradox highlighted by Sachs and Warner (1995), countries rich in natural resources tend to have poor performance compared to countries that are not endowed in natural resources. Consequently, resource abundance is identified as a significant determinant of economic failure. While most studies on the so-called "resource curse" paradox look at the negative growth effects of commodity abundance/dependence, they usually, with a few exceptions, overlook the impact of volatility channel. Our main objective is to investigate whether the abundance of natural resources per se is a curse or if the observed negative effects on growth could be due to the volatility of natural resource revenue. We will also investigate whether there is a role for financial development in offsetting some of the negative effects of volatility. This is particularly important for primary-product abundant countries, where resource revenues are highly volatile.

Little consensus exists on the effect of natural resource richness on economic growth and the mechanism underlying the effect. A number of transmission channels have been identified in the literature in order to describe the resource curse. These channels can be divided into two different but overlapping categories: economic and political explanations.

The first classical economic explanations for the resource curse is based on Dutch disease theory.



The term “Dutch disease” derives from the Netherlands’ experience of a declining manufacturing sector after the discovery of large natural gas reserves in the 1950s. The models for Dutch disease that were developed by Corden and Neary (1982) and Van Wijnbergen (1984) show how a new discovery of natural resources in a country may harm national income via negative effects on the learning by doing mechanism and other mechanisms in manufacturing sectors. The adverse effects can emerge because natural resources exploitation draws labor out of the manufacturing towards the extractive sector due to more attractive returns to labor supply. As a result, the manufacturing sector experiences shortage of labor and higher input costs. On the other hand, a rise in mining revenues leads the government to raise its spending which will partly be spent on non-traded goods such as construction and services. The prices of non-traded goods and services increase, and this leads to an appreciation of the real exchange rate. As a result, economic growth declines as manufacturing output and non-commodity exports drop due to both higher labor costs in manufacturing, and higher real exchange rate that makes non-commodity exports more expensive and less competitive. Thereafter, Krugman (1987) and Matsuyama (1992) developed a series of theoretical models for “Dutch disease” for which they all assume that productivity growth in the manufacturing sector is driven by learning by doing. They discuss how Dutch disease can appear through different channels such as increasing returns to scale trade, agricultural productivity and exchange rate volatility. More recent academic work expands on the existing models and derives different interpretations concerning Dutch disease (Torvik, 2001; Sachs and Warner, 2001; Matsen and Torvik, 2005; Van der Ploeg and Venables, 2013; Cherif, 2013). The other economic channels include resource price volatility. The primary source of revenue in resource rich countries tended to be the extractive sector. However, commodity prices may fluctuate significantly, which hinders governments’ ability to properly manage their rent. The macroeconomic instability that results from resource price volatility can also discourage investment (Van der Ploeg and Poelhekke, 2009). Recent propositions have been made around the volatility channel. Van der Ploeg and Poelhekke (2009) argued that the positive effects of natural resources on growth are trumped by their adverse indirect effects through the volatility. In fact, natural resources are known to exacerbate macroeconomic volatility (Bleaney and Halland, 2009; Malik and Temple, 2009; Frankel, 2010), while empirical studies confirm a negative relationship between volatility and growth (Aizenman and Pinto, 2004; Loayza and Hnatkovska, 2004; Ramey and Ramey, 1994). Macroeconomic volatility is found to have significant costs in terms of decline in economic growth, loss in welfare, and increase in inequality and poverty (Aizenman and Pinto, 2004).

Moving further along the spectrum from economic to political causal channels for the resource curse,

we come to rent seeking, or the “Political Dutch Disease” as labelled by Lam and Wantchekon (2003). People seek political rents when they try to obtain benefits for themselves through their political influence. According to Sachs and Warner (2001), Hodler (2006) and Iimi (2007) the natural resource revenues increases the power of elites, who have the capacity to widen income inequalities in some countries. The elites or powerful groups generally take a large share of these revenues and distribute it for the benefit of their immediate circles rather than investing it to upgrade infrastructure and sustainable economic development. Natural resource revenues may be the major source of conflict between domestic stakeholders such as politicians, local tribes, and citizens more broadly (Sala-i Martin and Subramanian, 2013; Davis and Tilton, 2005). Collier and Hoeffler (2004) finds that in Africa, the probability of a civil war ranges from less than 1% in resource poor countries to nearly 25% in resource rich one (Ross et al., 2011). The other main political channels suggest that weak institutions are the main reason of the resource curse (Arezki and van der Ploeg, 2010; Robinson et al., 2006). Natural resources may have a negative impact on institutions: resource rich countries tend to have centralized government with collusion between governments and the mining industry. In addition, resource revenues can be used to calm citizen protestation, repress the opponents and avoid accountability pressure (Karl, 1997). Natural resource abundance surges the level of corruption in countries where democratic institutions are weak but the same results does not hold in countries where democratic institutions are strong (Bhattacharyya and Hodler, 2010). Tornell and Lane (1999) consider weak institutions responsible for the slow growth experienced in Nigeria, Mexico and Venezuela after oil was discovered in these countries. Sala-i Martin and Subramanian (2013) find that the corruption that emerged after the discovery of oil was responsible for the slow growth experienced by Nigeria. Finally, Mehlum et al. (2006) also claim that good institutions are essential to solving the resource curse.

The empirical evidence on the natural resource curse paradox is mixed. Rodriguez and Sachs (1999); Gylfason (2001) among others confirm Sachs and Warner’s results of negative effect of the level of resource abundance on economic growth. However, Brunnschweiler and Bulte (2008) claim that the resource curse is no longer valid when one uses the correct measure of resource abundance (rather than dependence) in regressions. Indeed, there is a growing number of articles providing evidence against the paradox of the resource curse. Alexeev and Conrad (2009) and Cotet and Tsui (2013) find no empirical support the natural resource curse paradox. Quite the opposite, studying nations with large oil endowments, they find that these nations exhibit higher income growth. In addition, Smith (2015) assesses the impact of major oil discoveries since 1950 on GDP per capita. Using different quasi-experimental methods such as the synthetic control method, he finds that oil

discoveries impact positively long run growth.

To sum up, the results of the literature remain mixed, whether natural resource abundance or natural resource dependence causes the resource curse. Furthermore, all these studies generally focus on the effects of either natural resource abundance or natural resource dependence as natural resource wealth indicator on economic growth. Indeed, there is hardly any study, which looks into the individual effects of both indicators. The first contribution of this paper to the literature is to investigate both the direct effect of natural resource abundance and dependence on growth. Secondly, we assess the indirect effect of natural resources on growth performance via natural resource revenue volatility. Furthermore, we contribute to the literature by examining the channels through which the volatility effect operates, notably investment, human-capital, and institutional quality. We also investigate whether there is a role for financial development in offsetting some of the negative effects of resource revenue volatility. Indeed, theoretical literature has examined the potential of finance to mitigate volatility through its ability to enable agents to diversify risk. Acemoglu and Zilibotti (1997) argue that better diversification allows funds to be gradually allocated to their most productive use, with more productive specialization reducing growth variability. However, evidence on volatility reducing aspects of finance is equally mixed. For example, Braun and Larrain (2005) and Raddatz (2007) find that financial development reduces output volatility, while Easterly et al. (2001) establish a U-shaped relationship between volatility and depth in the financial sector.<sup>2</sup> Denizer et al. (2002) generally supported a negative correlation between financial depth and investment growth, consumption and volatility. However, Acemoglu et al. (2003) argued that such a relationship is not strong. A more recent article by Dabla-Norris and Srivisal (2013) provides results on finance volatility impacts that reflect those of Cecchetti and Kharroubi (2012) on the finance growth impacts: financial depth plays a key role in mitigating volatility of output, consumption and investment, but only to some degree. At very high levels, such as those prevailing in many advanced economies, financial depth exacerbates the volatility of consumption and investment.

Methodically, we test the above hypothesis using panel data covering the period 1985–2015 and 103 countries. The use of panel data is a significant departure from most existing studies on the resource curse, which typically present results driven by cross-country variation. In addition to the standard fixed effect methodology which still imposes a high degree of homogeneity, this empirical study is conducted using the panel smooth transition regression (PSTR) approach developed by González et al. (2004). The PSTR approach is a more intuitive and flexible methodology than the

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2. Financial depth corresponds to the ratio of private credit to gross domestic product GDP.

polynomial models widely used in the literature. It allows the impact of resource rent, investment, human capital and institutional quality to smoothly move from one regime to another depending on the value of a threshold variable (here, volatility of resource rent). Since the impact of the natural resource rent may depend on the level of rent volatility, it is consistent with the definition of a threshold regression model. The PSTR approach offers a simple parametric approach. It allows to capture both the heterogeneity between countries and the temporal variability of the impact of resource rent, investment, human capital and institutional quality as a function of the level of rent volatility. In other words, the PSTR approach allows for smooth changes in country specific correlations depending on the level of rent volatility. Finally, we introduce resource revenue volatility rather than commodity price volatility (see, for instance, Cavalcanti et al., 2015) because the volatility of commodity prices is not the only factor impacting resource rich economies. Basically, in most economies natural resource price volatility and production/export revenue volatility are very similar. This is attributable to the fact that production and exports generally remain relatively stable over time, with some small year-to-year variations. However, political tensions and conflicts (for instance, wars, and sanctions) in oil-producing regions have led to several supply disruptions and restrictions. As a result, volatility in natural resource prices was not the only factor that affected economies with abundant natural resources. The volatility of natural resource production and exports was also an important feature of the post-1970 period. Indeed, as shown in the theoretical growth model of Esfahani et al. (2014) for oil-exporting countries, it is volatility of export revenues that matters. Therefore, the combined effects of price and quantity volatility should be both taken into account.<sup>3</sup>

The estimation results confirm that, in contrast to the predictions of the resource curse and Dutch disease literature, a higher natural resource abundance significantly raises economic growth while a higher resource dependence have no impact on economic growth. In addition, our empirical findings also reveal a significant negative effect of resource rent volatility on output growth. Indeed, GDP growth loss may reach 17 percentage-point per year between countries characterized by low natural-resource rent volatility and those by high natural resource rent volatility. Consequently, we claim that volatility of natural resource rent, rather than abundance as such, that drives the resource curse paradox. We also find that two operating channels of the resource curse are human and physical capital. Furthermore, using data on financial development, our results illustrate that a better financial development can offset some of the negative effects of rent volatility.

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3. The Libyan civil war in 2011 and persistent geopolitical tensions over Iran's nuclear program are a perfect example of the disruption of supply for these countries.

The remainder of the paper is structured as follows. Section 2 discusses why volatility may harm output growth. Section 3 presents the data. Section 4 discusses our empirical specification. Section 5 presents the empirical evidence. Section 6 concludes.

### **3.2 Why might the volatility of natural resource revenues hinder growth?**

In recent decades, output volatility was perceived mainly as a fleeting business cycle phenomenon of secondary concern for longer-term development objectives. Theoretical advances have since combined short and long-term fluctuations into a single framework, while a growing body of research suggests that higher volatility is associated with lower growth. Volatility has therefore occupied a more central place in the development debate. One of the main messages of this paper is that the natural resource revenues volatility should be considered in the growth analysis alongside of other determinants of output per capita. It really matters because one of the economic channels through which the resource curse may operate is the volatile nature of natural resource prices in global markets and natural resource production volatility due to political factors (for instance, wars, and sanctions).

Overall, variability in resource income can affect economies at a global level in several ways, quite apart from trends in commodity price (Manley et al., 2017; Frankel, 2010). This effect will be mostly negative when volatility is associated with economic uncertainty, whether from political insecurity (Alesina and Perotti, 1996), macroeconomic instability (Judson and Orphanides, 1999) or institutional weaknesses (Rodrik, 1991; Serven et al., 1997). The theoretical basis for a negative effect of uncertainty on economic growth is based on conditions of risk aversion, aversion to poor performance, clumsiness and irreversibility associated with the investment process. In addition, the distinction between the ex-ante effects of volatility and the ex-post effects is important. The ex-ante effects of uncertainty will arise from agents' decisions to transfer their allocations between risky and risk-free activities. Ex-post effects occur when agents adjust their expectations of future income to current income or when they adjust their current expenditure plans to income deficits that they consider impossible or too costly to cover through borrowing. Under these conditions, uncertainty may lead companies to under-invest or invest in "bad" projects (Bertola and Caballero, 1994). Davis and Tilton (2005) argue that commodity price volatility leads to pro-cyclical fluctuations in government and export revenues, both of which decline during periods of declining prices.

This makes it more difficult to plan spending and align public finance revenues and expenditures, which in turn can reduce the effectiveness of public and private investment. Indeed, if the government spends all or most of the windfall revenues, then practically all the increase in aggregate demand due to the windfall takes the form of government expenditure. The government becomes the booming sector. One way or another, when revenues fall, the shock will be transmitted to the rest of the economy. Maintaining high levels of expenditure will not be sustainable, while reducing expenditure in line with declining revenues will have a direct impact on aggregate demand. Thus, when public expenditure is determined by current revenues, if revenues are volatile, fiscal policy and aggregate demand also become volatile. These fluctuations in fiscal spending affect the volatility of the real exchange rate and lead governments to rely more heavily on import tariffs and other trade-distorting taxes to generate revenue and manage the resulting loss of competitiveness in the non-oil sectors. This would be in addition to the higher production costs typical of oil-exporting economies. Furthermore, volatility in natural resource revenue can also reduce countries' ability to meet the conditions required for counter-cyclical expansionary monetary policy when it would otherwise be beneficial. Similarly, Humphreys et al. (2007) argue that the magnitude of resource price fluctuations can be amplified by international lending. When commodity prices are high, commodity-rich countries borrow abroad, exacerbating the boom. When prices fall, international lenders demand repayments and force expenditure reductions, which increases the extent of slow-downs. This response/counter-reaction pushed many resource rich countries into debt crises in the 1980s (Van der Ploeg, 2011). Van der Ploeg and Poelhekke (2009) highlight the causal links between price volatility and growth. They argue and present evidence that output growth per capita is negatively affected by the volatility of unexpected output growth, which is itself caused by the high volatility of world resource prices in countries that are highly dependent on them. They point out that countries whose share of natural resource exports in GDP is greater than 19% have a standard deviation of output growth of 7.37%. In comparison, the standard deviation is only 2.83% for countries with a natural resource export to GDP ratio of less than 5% (see also Joya, 2015).

Van der Ploeg and Poelhekke (2009), who challenge the "traditional resource curse" hypothesis, are closely related in motivation to our paper. our paper is different in many respects to their work: we consider the effects of natural resource rent volatility rather than the volatility of unexpected GDP growth on economic output. We also investigate the crowding out effect of rent volatility on different channels like investment and human capital. In addition, our econometric methodologies are also different from theirs, since they use the Maximum Likelihood (ML) fixed effects panel techniques,

while we use the OLS fixed effect and panel smooth transition model approaches. Therefore, we see our article as complementary to theirs.

### **Preliminary evidence from correlation**

As noted in some of the most recent literature on the topic (see introduction), there seems to be growing support for the view that the volatility in commodity prices and revenues in particular drives the resource curse paradox. See, for instance, Cavalcanti et al. (2015). In Figure 3.1 we plot the relationship between real GDP per capita growth and its volatility (measured by its standard deviation over the full sample).<sup>4</sup> In this case, we see a rather clear negative relationship between the two variables.<sup>5</sup> The observation that higher volatility in output dampens growth was in fact discussed extensively in the seminal paper of Ramey and Ramey (1994). However, we also note that there is a positive relationship between the volatility in natural resource revenue and GDP growth suggesting therefore, that there seems to be some evidence that the volatility in natural resource prices and production is associated with higher volatility in GDP growth, which in turn has a negative effect on output growth.

In order to explore the channels through which the use of natural resource revenue may influence GDP/Capita growth rates, Figure 3.2 presents the relationship between the Human Capital Index (HCI) and GDP/capita growth against the volatility of natural resource rent. These relationships are clearly negatively related, suggesting that human capital and volatility of natural resource rents can be the channels through which the resource curse is transmitted. This is consistent with the intuitive nature of Figure 3.1 that volatility in natural resource and production prices is associated with a negative effect on output growth. Moreover, such volatility appears to negatively impact growth through human capital. Volatility will reduce the human capital accumulation, which is itself a significant driver of growth.<sup>6</sup>

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4. All graphs are drawn from a sample of 103 countries available 3.4 in appendix.

5. The correlations displayed on the left panel of Figure 1 seem not significant. Indeed, after testing for significance of the correlation coefficient, we find them to be not significant even at 10% level.

6. The correlations displayed on the right panel of Figure 2 seem not significant. However, after testing for significance of the correlation coefficient, we find them to be significant at 5% level.

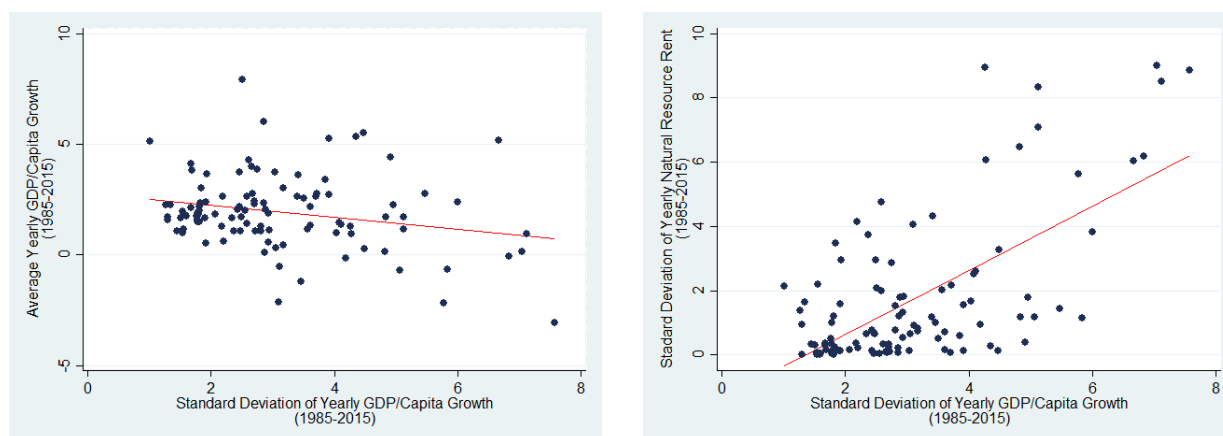


Figure 3.1: Scatter Plots of GDP/Capita Growth and Volatility of Natural Resource Rent against Volatility of GDP/Capita Growth.

Source: World Bank national accounts data.

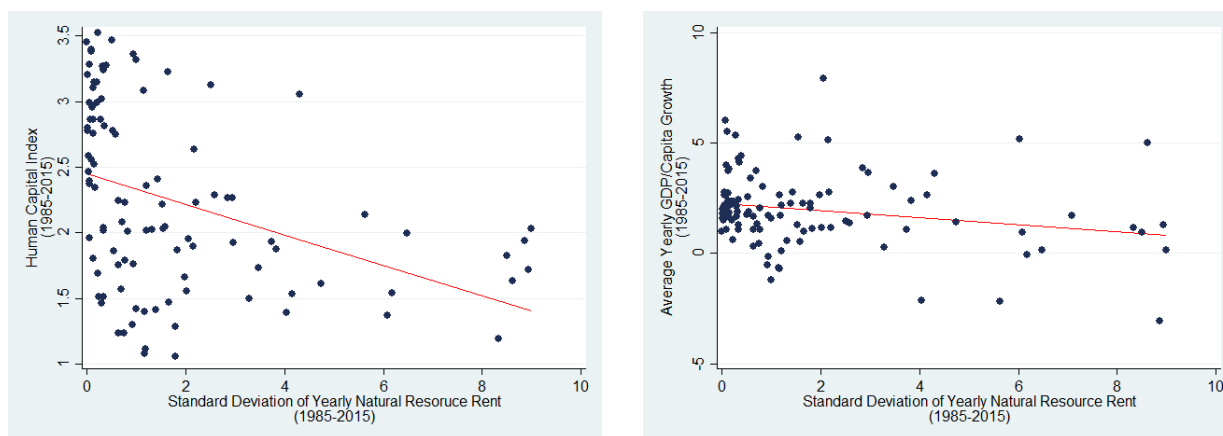


Figure 3.2: Scatter Plots of Human Capital Index and GDP/Capita Growth against Volatility of Natural Resource Rent.

Source: World Bank national accounts data.

### 3.3 Data

To empirically investigate the relationship between economic growth and resource rents together with rent volatility, we use a panel dataset with a cross-sectional dimension of 103 countries and a time dimension from 1985 to 2015. Due to data limitations, not all specifications cover exactly 103 countries and in most specifications, the panel is unbalanced. We use data on real GDP growth per capita, a measure of resource rents based on prices, costs of production and quantities of 13 commodities, and other significant drivers of growth such as the initial level of GDP per capita, the share of investment in GDP, human capital, trade openness, GDP volatility, corruption and



government stability.<sup>7</sup> Since we are also interested in testing whether or not resource dependence weaken growth in our sample of countries, we use a measure which is the average share of primary products in total merchandise and service exports. As well, in order to verify whether finance can offset the negative growth effects of resource rents volatility, we use a measure of financial development. A more detailed description of the data and their sources are provided in Table 3.5.

In order to capture the long-run growth effects of resource rent and volatility and filter out business cycle fluctuations, we follow the literature in transforming the annual series into non-overlapping and overlapping five-year averages depending on the estimation strategy. For the within strategy, since our data set covers the period 1985-2015, we can build an unbalanced panel with at most six five-yearly observations per country. For the PSTR model, given that our data set covers the period 1989-2015, we build an unbalanced panel with at most 27 five-yearly observations per country.<sup>8</sup>

Our main independent variables are natural resource abundance, natural resource dependence and volatility of natural resource abundance. The natural resource abundance measure is the ratio of resource rents to GDP ( $NRA_{it}/GDP_{it}$ ). These rents include rents from energy and minerals and are based on the World Bank development indicator. The rent from a particular commodity is defined as the difference between its world price and average extraction costs both expressed in current US dollars. The world price of a particular commodity is global and only varies over time. The extraction costs however are variable over time and across countries. We use this measure of natural resource revenues for the following reasons. First, by measuring resource rents, it is a good proxy for resource revenues that can potentially be appropriated by political leaders. Second, it is fairly wide in terms of country coverage. Therefore we are able to minimize the risk of sample selection bias. It also provides a reasonably long time dimension. Third, it may help to bypass some endogeneity related concerns as resource rents predominantly depend on the stock of natural resources and exogenous world prices. Fourth, it has been used in a number of recent studies (e.g., Bhattacharyya and Hodler, 2010; Collier and Hoeffler, 2009). The natural resource dependence is the ratio share of primary products in total merchandise and service exports. A departure in comparison to earlier studies is through the use of the share of primary commodity exports rather than primary commodity exports divided by GDP see (Dietz et al., 2007). The GDP share equals the percentage share of exports multiplied by the percentage share of exports in GDP, the latter being significantly influenced by factors not related to natural resource specialisation such

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7. GDP volatility corresponds to the standard deviation of GDP per capita growth over the years  $t - 4$  to  $t$ .

8. Overlapping five-year averages approach allows us to work in a long-term perspective, as in the within estimations, while having a significantly greater time dimension, a required condition for the PSTR's robustness.

as country size as well as distance to trading partners (see Guttman and Richards (2006) for a cross-country investigation of trade openness). For this reason, we view the share of exports in primary commodities as a cleaner measure.

To investigate the consequences of volatility of natural resource revenues for long-run growth and the growth volatility, and given that we want to utilize the time-varying dimension of volatility (in contrast to most studies in the growth literature which employ time-invariant measures of volatility), we consider the five year non-overlapping standard deviation of the annual resource rents. We rely on a measure of realized natural resource revenue volatility, see El-Anshasy et al. (2017) for more details. Our measure of realized natural resource volatility is then given by the five year non-overlapping standard deviation of the annual resource rents,  $w_{R,it}$ :

$$\sigma_{R,it,t+s} = \sqrt{\frac{1}{S} \sum_{s=0}^S (w_{R,it+s} - \frac{1}{S+1} \sum_{s=0}^S w_{R,it+s})^2} \quad (3.1)$$

where  $S = 4$  as we are using five-year averages.<sup>9</sup> The volatility ( $\sigma_{R,it,t+s}$ ) indicates the extent to which resource rent ( $w_{R,it}$ ) deviates from a given mean at any point in time.

In addition, when discussing economic growth, it is necessary to consider institutional quality. If we do not control for institutional quality in the regression, we could falsely conclude that natural resource abundance is the reason for slow economic growth when the problem is actually institutional quality. Accordingly, a proxy variable for institutional quality is included in the regression. There are six indices estimating institution quality contained in the International Country Risk Guide (ICRG). The most relevant index for the purposes of our analysis is the government stability and corruption index.<sup>10</sup> Other control variable in the model include, a measure of human capital level in a country which is based on years of schooling and returns to education, and a gross capital formation variable is used as a measure of investment level in a country - formerly this variable is referred to as gross domestic investment. It includes net changes in inventories and fixed assets

9. In the PSTR modelisation, our measure of realized natural resource rents volatility is then given by the five year overlapping standard deviation of the annual resource rents.

10. The ICRG index of government stability and corruption comes from Political Risk Services Inc., a private-owned firm that annually produces the ICRG database, that quantifies political, economic and financial risks in general. Government stability assesses the government's ability to deliver the programs it has declared and its ability to remain in office. The risk rating assigned is the sum of three sub-components: government unity, legislative force and popular support. The corruption index reflects different aspects of corruption, particularly within the political system. More specifically, it includes requests for specific payments and bribes related to import and export licences, exchange controls, tax assessments, abusive favouritism, nepotism and secret financing of supporters.

which consist of land improvements, machinery, equipment purchases, plant, private residential, railways, construction of offices, schools, hospitals and commercial buildings. We also control for trade openness. It is the sum of exports and imports of goods and services measured as a share of GDP. Sachs and Warner (1995) hypothesize that natural resource rich countries are more likely to employ protectionist policies such as import substitution and state-led development plans. To combat the effect of Dutch disease and the decline of non-resource sectors, resource rich countries may adopt protectionist trade policies such as high tariffs and quotas.

Finally, in order to assess if financial development can moderate the impact of rent volatility, we use the ratio of private credit to GDP as our main measure of financial development ( $PC_{it}/GDP_{it}$ ).<sup>11</sup> This ratio is taken from Beck et al. (2000), and is widely used in the literature (Acemoglu and Johnson, 2005; Beck et al., 2003). It takes into account credits from banks and other financial institutions to firms and households. This ratio suggests that a country is financially underdeveloped if there is little credit available for the private sector relative to the size of its economy. For our purpose its main advantage is that it covers the relevant time period and the largest number of countries. This allows us to use panel data and minimizes the sample selection bias both across countries and over time.

### 3.4 Empirical model

This section introduces the two econometric techniques used in our empirical analysis in section 5. They are: (1) a fixed effect approach which is a homogeneous slope panel method and (2) panel smooth transition model (PSTR) that allows for slope heterogeneity in time and between individuals (a heterogeneous panel approach).

#### 3.4.1 Standard specification

To test more systematically whether there is a resource curse, we firstly rely on the following form:

$$\begin{aligned} Growth_{it} = & \alpha_0 + \alpha_1 NRA_{it} + \alpha_2 NRD_{it} + \alpha_3 VNRA_{it} + \alpha_4 (VNRA_{it} * NRA_{it}) \\ & + \theta' X_{it} + \lambda_i + \gamma_t + \epsilon_{it} \end{aligned} \quad (3.2)$$

---

11. One may argue that many of the potential explanatory variables (e.g. financial development, openness and institutional quality) are correlated. However, considering that we use a government stability index to proxy institutional quality, we do not face to this problem. Table 3.12 shows the correlation matrix between usual proxies of institutional quality and financial development and trade openness.

where *Growth* is the real growth rate of gross domestic product per capita, *NRA* is the natural resource rents as percentage of GDP i.e. natural resource abundance, *NRD* is the ratio share of primary products in total merchandise and service exports i.e. natural resource dependence, *VNRA* is the resource rent volatility. *X* is a set of seven control variables used in the literature to explain the GDP growth. They can be divided into two different categories. The first set of controls is comprised of economic controls measures: index of human capital based on years of schooling and returns to education, investment measured as fixed capital formation divided by GDP, openness measured as export plus import divided by GDP and the volatility of GDP.<sup>12</sup> The second set includes institutional and financial variables. The institutional quality measured by corruption and government stability index. Financial development is defined by domestic credit to private sector as a share of GDP.

The  $\lambda_i$  is unobserved effect which is called individual effect or individual heterogeneity when *i* is indexed as individual. Now, the question is how to treat  $\lambda$ ? While panel data has a cross-sectional and a time dimension, the use of country fixed effects (which is akin to inserting a dummy variable for each country) ensures that our estimates of the coefficients of interest are only driven by the variation within countries over time. The reason is that the country fixed effects control for time invariant country specific factors, such as initial endowments, legal origin, and social capital. Moreover, the year dummy variables control for time varying common shocks and spurious business cycle effect Keller (2004).

Firstly, in order to filter out business cycle fluctuations and to introduce the natural resource rent volatility variable and also to focus on the long-run effects of *NRA*, *NRD* and the volatility *VNRA*, we follow the literature in transforming the annual series into at most six non-overlapping five-year average (all variables are taken as averages over each five year period).

$$\begin{aligned} Growth_{it} = & \alpha_0 + \alpha_1 NRA_{it} + \alpha_2 VNRA_{it} + \alpha_3 (VNRA_{it} * NRA_{it}) + \alpha_4 (VNRA_{it} * FD_{it}) \\ & + \theta' X_{it} + \lambda_i + \gamma_t + \epsilon_{it} \end{aligned} \quad (3.3)$$

Secondly, in order to investigate if financial development may have a dampening effect on resource revenue volatility, we rely on equation (3.3). To this end, an interaction term is introduced within the model ( $\alpha_4$ ). It allows to assess how financial development will impact the relationship between natural resource rent volatility and economic growth.

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12. Based on a common approach in the literature (e. g. Caselli, 2005), the PWT version 8 used an index of human capital defined by the average years of schooling of Barro and Lee (2013) and an assumed rate of return on education based on estimates from the Mincer equation in the world (Psacharopoulos, 1994)

### 3.4.2 Panel smooth transition model

#### Threshold specification

In order to release the assumption of high degree of homogeneity, we rely on the panel smooth transition regression (PSTR) approach developed by González et al. (2004). This is a generalization of the panel threshold regression (PTR) model by Hansen (1999).

The PSTR model is:

$$\begin{aligned} Growth_{it} = & \alpha_1 NRA_{it} + \alpha_2 INV_{it} + \alpha_{it} HCI_{it} + \alpha_x AGSTAB_{it} \\ & + (\alpha'_1 NRA_{it} + \alpha'_2 INV_{it} + \alpha'_3 HCI_{it} + \alpha'_4 GSTAB_{it}) * g(VNRA_{it}, \gamma, \delta) \\ & + \theta X'_{it} + \lambda_i + \epsilon_{it} \end{aligned} \quad (3.4)$$

where  $Growth_{it}$  denotes the real growth rate of gross domestic product per capita,  $NRA$ ,  $INV$ ,  $HCI$ ,  $GSTAB$  are the time-varying explanatory variables (regime dependent variables), namely natural resource abundance, investment, human capital index and government stability index.  $X_{it}$  is the vector of time-invariant regressors (regime independent variables), namely trade openness, financial development, corruption and volatility of GDP. Finally,  $\lambda_i$  denotes an individual fixed effect and  $\epsilon_{it}$  is the idiosyncratic error.

The transition function is given by a logistic function:

$$g(VNRA_{it}, \gamma, \delta) = [1 + \exp(-\gamma(VNRA_{it} - \delta))]^{-1}, \gamma > 0 \quad (3.5)$$

This function is continuous and bounded between [0,1]. It depends on the transition variable which is the volatility of resource rent,  $VNRA_{it}$ , a threshold or location parameter  $\delta$  and a smooth parameter  $\gamma$ . If the parameter  $\gamma$  tends to infinity, the transition function  $g(VNRA_{it}, \gamma, \delta)$  tends to the indicator function, the transition is sharp as in a panel threshold regression (PTR) model developed by Hansen (1999). When  $\gamma$  tends to zero the transition function  $g(VNRA_{it}, \gamma, \delta)$  is constant and the model corresponds to a standard linear model with individual effects (so-called within model), which means constant and homogeneous elasticities. The PSTR has a great advantage: it allows the effect of  $NRA$ ,  $INV$ ,  $HCI$ ,  $GSTAB$  to vary with the level of the resource rent volatility.<sup>13</sup> The impact of resource rent on growth depending on the level of resource rent volatility is given

13. In the rest of this section, for simplification purposes, we will consider the PSTR model with a single time varying variable which is the resource rent.

by:

$$e_{it} = \frac{\partial Growth_{it}}{\partial NRA_{it}} = \alpha_1 + \alpha'_1 g(VNRA_{it}, \gamma, \delta) \quad (3.6)$$

The properties of the transition function entail  $\alpha_1 \leq e_{it} \leq \alpha_1 + \alpha'_1$  if  $\alpha'_1 \geq 0$  or  $\alpha_1 + \alpha'_1 \leq e_{it} \leq \alpha_1$  if  $\alpha'_1 \leq 0$ .

The PSTR model can be generalized to  $r + 1$  extreme regimes as follows:

$$Growth_{it} = \alpha_1 NRA_{it} + \sum_{j=1}^r \alpha'_j NRA_{it} * g_j(VNRA_{it}, \gamma_j, \delta_j) + \lambda_i + \epsilon_{it} \quad (3.7)$$

where the transition functions  $g_j(VNRA_{it}, \gamma_j, \delta_j)$  depend on the slope parameters  $\gamma_j$  and on the location parameters  $\delta_j$ . In this generalization, the marginal impact of natural resource rent on growth is given by:

$$e_{it} = \frac{\partial Growth_{it}}{\partial NRA_{it}} = \alpha_1 + \sum_{j=1}^r \alpha'_j g_j(VNRA_{it}, \gamma_j, \delta_j) \quad (3.8)$$

### Estimation and specification test

The estimation of the parameters of the PSTR model consists of eliminating the individual effects  $\lambda_i$  by removing individual specific means and then by estimating the transformed model by non linear least squares (González et al., 2004). González et al. (2004) propose a procedure that consists (i) to test the linearity against the PSTR model and (ii) to determine the number,  $r$ , of transition functions, i.e. the number of extreme regimes which is equal to  $r + 1$ .<sup>14</sup> Testing the linearity in Eq.(3.7) can be done by testing  $H_0 : \gamma = 0$  or  $H_0 : \alpha'_1 = 0$ . However, in both cases, the test is not standard since under  $H_0$  the PSTR model contains unidentified nuisance parameters. To solve this problem, the transition function  $g(VNRA_{it}, \gamma, \delta)$  can be replaced by its first-order Taylor expansion around  $\gamma = 0$  and to test an equivalent hypothesis in an auxiliary regression:

$$Growth_{it} = \alpha_1 NRA_{it} + \Theta_1 NRA_{it} VNRA_{it} + \lambda_i + \epsilon_{it}^* \quad (3.9)$$

14. The parameters  $\alpha$  and  $\alpha'$  correspond to the estimated parameters for extreme regimes i.e.  $\alpha$  represents the coefficient when the transition function  $g(VNRA_{it}, \gamma, \delta)$  tends towards 0 and the sum of  $\alpha$  and  $\alpha'$  represents the coefficient when the transition function tends towards 1. Between these two extreme regimes, the PSTR model allows coefficients to vary across countries and over time according to the transition value, the coefficient of the  $it$  country at time  $t$  is defined as a weighted average of  $\alpha$  and  $\alpha'$  in Eq 3.4.

In this first-order Taylor expansion, the parameter  $\Theta_1$  is proportional to the slope parameter  $\gamma$ ,  $\epsilon_{it}^* = \epsilon_{it} + R\Theta_1 VNRA_{it}$  and  $R$  is the remainder of Taylor expansion. Thus, testing the linearity of rent volatility impact against the PSTR model simply consists of testing  $H_0 : \Theta_1 = 0$  in Eq.(3.9). Then, some standard tests can be applied. Let  $SSR_0$  denotes the panel sum of squared residuals under  $H_0$  (linear panel model with individual effects) and  $SSR_1$  the panel sum of squared residuals under  $H_1$  (PSTR model with two regimes), three statistics can be computed: Wald test (Lagrange Multiplier test)  $LM$ , its Fisher-version  $LM_f$  and pseudo Likelihood-ratio test  $LRT$ :

$$LM = TN[SSR_0 - SSR_1]/SSR_1 \quad (3.10)$$

$$LM_f = [SSR_0 - SSR_1]/[SSR_1/(TN - N - 1)] \quad (3.11)$$

$$LRT = -NT[\log(SSR_1) - \log(SSR_0)] \quad (3.12)$$

Under the null hypothesis,  $H_0$ ,  $LM$  statistic is distributed as a  $\chi^2(1)$ ,  $LM_f$  has an approximate  $F(1, TN-N-1)$  distribution and  $LRT$  has also a  $\chi^2(1)$ . Similar methodology is used when it comes to testing the number of transitions functions in the model or equivalently the number of extreme regimes. If the linearity hypothesis is rejected, the sequential approach consists by testing the null of hypothesis of no remaining non linearity in the transition function. The issue is then to test whether there is one transition function or whether there are at least two transition functions defined as:

$$Growth_{it} = \alpha_1 NRA_{it} + \alpha'_1 NRA_{it} g_1(VNRA_{it}, \gamma_1, \delta_1) + \alpha'_2 NRA_{it} g_2(VNRA_{it}, \gamma_2, \delta_2) + \lambda_i + \epsilon_{it} \quad (3.13)$$

As in the case of one transition function, the test relies on replacing the second transition function with its first-order Taylor expansion around  $\gamma_2 = 0$  and then in testing the linear constraints on the parameters. By using this first-order Taylor expansion, the model becomes

$$Growth_{it} = \alpha_1 NRA_{it} + \alpha'_1 NRA_{it} g_1(VNRA_{it}, \gamma_1, \delta_1) + \Theta_2 NRA_{it} VNRA_{it} + \lambda_i + \epsilon_{it}^* \quad (3.14)$$

Let  $SSR_0$  denotes the panel sum of squared residuals under  $H_0$  (the PSTR model with one transition function). Let  $SSR_1$  denotes the sum of squared residuals of the transformed model Eq.(3.14). As above, the test statistics can be calculated in the same way by adjusting the number of degrees of freedom. The sequential procedure is then as follows. Given a PSTR model with  $r = r^*$ , test the

null  $H_0 : r = r^*$  against  $H_1 : r = r^* + 1$ . If  $H_0$  is not rejected the procedure stops. Otherwise, the null hypothesis  $H_0 : r = r^* + 1$  is tested against  $H_1 : r = r^* + 2$ . The testing procedure continues until the first acceptance of the null hypothesis of no remaining non linearity. As mentioned in González et al. (2004), given the sequential aspect of this testing procedure, at each step of the procedure the significance level must be reduced by a constant factor  $0 < \tau < 1$  in order to avoid excessively large models. As suggested by González et al. (2004) the value of  $\tau$  is set to 0,5.

## 3.5 Empirical results

### 3.5.1 Standard results

In this section, we first investigate if the abundance of natural resources per se is a significant factor in economic failure, or if failure to grow in commodity-rich economies can be linked to the volatility of rents on natural resources. Thereafter, we investigate the role of financial development in dampening and potentially offsetting the negative effects of resource rents volatility.

In order to drop out business cycle fluctuations while addressing the long-term effects of natural resource rent volatility, we follow the literature by using non-overlapping five-year averages. Given the time span of our dataset (from 1985 to 2015), we construct an unbalanced panel with a maximum of six-yearly observations per country covering 1985–2015. As regards PSTR results, we use overlapping five-year averages. This approach also allows us to work in a long-term perspective, as in the within estimations, while having a significantly greater time dimension, a required condition for the PSTR's robustness.<sup>15</sup>

### Resource abundance versus resource dependence

One of the essential questions in development and economic growth studies is how natural resource wealth affects long-term economic growth. The jury is still out, with approximately 40% of the empirical evidence documenting an adverse effect, 40% claiming no impact, and 20% revealing a positive impact (Havranek et al., 2016). The present study argue that a distinction should be made between natural resource abundance and resource dependence. Our main resource abundance variable may directly affect growth, but the influence may also be indirect through the level of

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15. To conduct a consistent analysis, we must ensure a large time dimension. But data availability for some countries is limited through time. As a result, we obtain a sample of 87 countries for the period 1989-2015.



resource dependence and volatility of resource revenue. We explicitly distinguish between such direct and indirect linkages in Eq.(3.2).

The results from testing the resource curse hypothesis Eq.(3.2) are summarized in Table 3.1. We estimate 5 different regressions that control for initial GDP per capita, investment, human capital, trade openness, volatility of GDP, finance development and institution quality. Table 3.1 presents the estimation results of the impact of natural resource abundance and its volatility as well as resource dependence on GDP per capita growth. Starting from regression (1), we observe that an increase in natural resource rent is both growth enhancing and highly significant. On the other hand, coefficient of natural resource dependence is negative and significant at 5% level. It shows the strong negative impact on growth of having a resource dependent economy. Despite the fact that resource dependence is measured somewhat differently from Sachs and Warner (1995), this result seems to corroborate their findings. However, regression (1) highlights a major difference: the direct effect of natural resource abundance has a positive impact on growth, in addition to the indirect negative effect through the resource dependence variable. This direct positive growth effect provides evidence against the traditional resource curse hypothesis which argues that it is the level of resource abundance that affects economic growth negatively (Ding and Field, 2005; Alexeev and Conrad, 2009; Brunnschweiler and Bulte, 2008)

Now that we have provided evidence against the unconditional resource curse, one concern with the foregoing analysis is the endogenous nature of the resource dependence variable. Indeed, Stijns (2005) is one of the first to point out this endogeneity issue due to the weak correlation between reserve data and resource dependence variable. In this context, it becomes relevant to assess whether resource dependence, i.e. the conventional variable of natural resources in resource curse literature, is still significant if it is treated as endogenous. Regression (2) provides estimation results of the 2SLS fixed effect when instrumenting for resource dependence as a function of several contextual factors as trade openness with its lags, and democracy to correct for omitted variables and reverse causality.<sup>16</sup> The strongest finding is that the effect of the resource dependent variable on growth performance initially found by Sachs and Warner (1995) is no longer statistically significant. This implies in particular that indirect effect of resource dependence, as shown in the regression (1), is not the main link between resource abundance and economic performance. The result in regression (2) also calls into question the consensus view that abundant natural resources negatively affect

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16. We also report the results of FE-IV for all models in Table 3.7, in order to check that the coefficient is still not significant. Moreover, knowing that we are in a panel data model, we rely on the lagged variables as instruments, which makes it much easier to find a good instrument compared to cross section-model. Test for instrument validity are available upon request.

economic growth even using the resource dependence variable. It confirms there is no curse also with the resource dependency variable once endogeneity is being accounted for.

Table 3.1: Fixed effect estimation results (regressions 1-5)

Method	Dependent variable: GDP growth per capita				
	1 FE	2 FE-IV	3 FE	4 FE	5 FE
Initial level of GDP	-0.016*** (-3.78)	-0.017*** (-4.92)	-0.014** (-4.67)	-0.013** (-5.08)	-0.013** (-5.03)
NRA	0.110** (2.62)	0.176*** (3.77)	0.159*** (3.50)	0.190*** (4.36)	0.175*** (4.03)
NRD	-0.019*** (-2.02)	-0.043 (-0.77)			
VNRA		-0.203** (-2.42)	-0.382** (-3.23)	-0.203 (-1.20)	-0.345 (-1.67)
VGDP	-0.263*** (-4.70)	-0.240*** (-3.99)	-0.256 (-5.79)	-0.259*** (-5.75)	-0.244*** (-5.41)
FD	-0.017*** (-2.99)	-0.012*** (-2.37)	-0.016*** (-2.92)	-0.017*** (-3.17)	-0.021*** (-3.68)
Government Stability	0.197*** (2.46)	0.196*** (2.23)	0.267*** (2.69)	0.279*** (2.77)	0.276*** (2.77)
Corruption	-0.451*** (-2.84)	-0.422*** (-2.59)	-0.517*** (-3.00)	-0.164*** (-2.98)	-0.544*** (-3.11)
Investment	0.049* (1.82)	0.071*** (2.71)	0.052** (2.30)	0.050** (2.44)	0.046* (1.65)
Human capital	-1.20 (-1.33)	-1.51 (-1.52)	-1.19 (-1.14)	-1.15 (-0.68)	-1.15 (-0.76)
Trade openness	0.010 (1.29)		0.015* (1.88)	0.015* (1.94)	0.016** (2.00)
NRA*VNRA				-0.011** (-2.22)	-0.009** (-2.01)
VNRA*FD					0.006* (1.72)
Constant	6.28** (2.00)	3.22 (1.23)	4.51 (1.52)	3.86 (1.34)	4.11 (1.44)
Observations	600	589	632	632	632
Number of countries	101	101	102	102	102
Time fixed effect	Yes	Yes	Yes	Yes	Yes

Note: T-statistics are in (); \*, \*\* and \*\*\* refer to the 10%, 5% and 1% significance levels, respectively. FE and FE-IV correspond to fixed effect and instrumental fixed effect estimations, respectively.

We are certainly not the first ones to show the positive effects of resource abundance on output growth. This is also supported by Cavalcanti et al. (2015) and Van der Ploeg and Poelhekke (2009). However, we take the argument further and try to establish that the indirect effect of natural

resources on growth is via the volatility rent channel (VNRA).

Regressions (2) and (3) of Table 3.1 show the opposite significant effects of NRA and VNRA on GDP growth in our sample. While natural resource rent boom significantly increases economic growth, volatility affects it negatively. This finding can be partly explained by the fact that fiscal and current account balances of natural resource rich countries are affected by swings in resources revenues with destabilizing effects on the macroeconomy. Therefore, the overall evidence in Table 3.1 shows that the source of the resource curse is the natural resource rent volatility rather than the resource abundance. These results,  $\beta_1 > 0$  and  $\beta_3 < 0$ , are still valid even when we control for all the traditional determinants of growth. Further evidence for the negative growth effect of the volatility channel is provided in Van der Ploeg and Poelhekke (2009) and Cavalcanti et al. (2015). Van der Ploeg and Poelhekke (2009) also point out the source of the resource curse as the volatility of commodity prices versus resource abundance, albeit their empirical approach is based on volatility of unexpected output growth and not on volatility of resource rents. VNRA is more relevant as the volatility of unexpected output growth is probably driven by a large number of factors that are not directly related to the abundance of natural resources.

In order to investigate the overall impact of natural resource rent variable and its volatility on economic growth, we add the interactions between the resource rent and its volatility in regression (4). The resulting coefficient is negative which implies that the total impact of resource rent is increasingly negative the higher a country's rent volatility. In fact, if rent volatility exceeds a given threshold, the negative growth effects of rent volatility offset the positive impact of resource rent booms, which suggests that volatility, rather than abundance per se, drives the resource curse paradox.

### **What is the potential role of financial development in dampening this negative effect of rent volatility?**

To investigate whether financial development can help offset some of the negative growth effects of rent volatility, we introduce an interaction term in our regressions between rent volatility and financial development. Table 3.1 regression (5) presents the result of the estimation carried out with the interaction term which echoes those obtained in previous regressions. It also suggests evidence regarding the dampening effect of financial development on the effect of resource rent volatility. As expected, the coefficient of the interaction term between VNRA and FD is both positive and significant. Therefore, a more developed financial market is likely to lead countries to

deal better with resource rent volatility and limit the pass-through of its adverse effect on growth by facilitating of borrowing constraints. Indeed, Aghion et al. (2005) argue that a more advanced financial intermediation makes borrowing against future cash flows easier. Their model predicts, then, that the negative effect of macroeconomic volatility on growth should be weaker in countries with more developed financial sectors.

Finally, in all specifications, we have controlled for other important determinants of growth such as initial level of GDP per capita, trade openness, investment, human capital, and institutional variables. We also control for the common time trend in fixed effect regressions. Including time trend controls for other factors such as technological progress which may affect the economic development of countries in our sample. Note that in all regressions, the control variables have the expected signs and are all statistically significant except for the human capital index in all regressions, and the trade openness in regression (1). For instance, the initial GDP per capita has a negative sign suggesting that the conditional convergence hypothesis is verified: countries having lower GDP per capita tend to grow faster. Investment (being essential inputs of physical capital accumulation) in a country increases the level of output in an economy because it generates employment opportunity which enhances the GDP per capita growth (Barro, 1996). The coefficient associated to trade openness is also positive (except in regression 1), which is consistent with both the neoclassical and endogenous growth theory. For the neoclassical case, the growth benefits of trade are based on comparative advantages (i.e. production factors endowments, technology differences). In the endogenous growth theory, trade affects economic growth positively through, for example, technological diffusion between countries (López-Villavicencio and Mignon, 2011). In all the specifications, the government stability index which stands for institutional quality has a significant positive impact on economic growth. Corruption is considered as one of the main problems in the process of development. However, the result indicates that corruption has a positive impact on growth which is in line with the "grease the wheels" hypothesis.<sup>17</sup> The general idea is that corruption facilitates beneficial transactions which should not have happened. As a consequence, it enhances the efficiency of the economy by allowing individuals in the private sector to correct or eliminate government failures (Méon and Weill, 2010). Bank credit to the private sector, expressing the level of financial development (King and Levine, 1993), is negatively related to growth. This result can be explained because financial development is often accompanied by financial instability that can be detrimental to growth (Guillaumont Jeanneney and Kpodar, 2005). Finally, compared

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17. Corruption may enhance efficiency because it allows companies and citizens to bypass the rules of an inefficient administrative and legal system that slows investment and therefore growth.

to what is commonly done, we have included the GDP volatility as a control variable. Its impact is significantly negative in all regressions. Aghion et al. (2005) argue that volatility creates uncertainty in firms' liquidity positions, and that discourages them from making productivity-enhancing investments. Therefore innovative investments are forgone and the economy stays on a low-growth path. Today, the idea that volatility and economic growth correlate negatively is quite widely accepted (Ramey and Ramey, 1994).

As a robustness check, we use an alternative measure of natural resource endowment. Table 3.6 in appendix reports the results when using natural resource rent per capita and its volatility instead of natural resource rent per GDP.<sup>18</sup> The results echoes those of Table 3.1. Indeed, natural resource rent per capita has a direct positive impact on economic growth when controlling for volatility impact. Volatility has a negative impact supporting the results of Table 3.1. However, the coefficient of the interaction term between VNRA and FD in regression (4) of Table 3.6 is not significant even at ten percent level. Therefore, we cannot confirm our previous results with the rent per capita variable on the dampening effect of the developed financial markets vis-à-vis volatility.<sup>19</sup> We also consider other variables such as inflation, population growth rate and exchange rate. Both inflation and population growth rate impact negatively GDP growth rate, as predicted by the theory. The exchange rate turns out to be not significant at five percent level. Overall the results are robust to adding further control variables (see Table 3.6 and Table 3.7).

### 3.5.2 PSTR results

Usually, studies on the natural resource curse have relied on classical linear models using interacting terms and may not address non-linear effects consistently. This type of specification is associated with two major limitations. First, the effect of natural resources on economic growth across countries is assumed to be the same. Nevertheless, this assumption is hardly valid. For instance, each country's natural resource endowment and production capacity are quite heterogeneous. Therefore, the level of oil income is likely to be different and its effect on economic growth also differs. Second, the standard approach assumes that the natural resource effect identified is constant over time.

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18. Table 3.7 column 5 provides the results of another robustness check, but in turn using instruments (trade openness with its lags, and democracy) for the natural resource rent variable. This robustness check is less used in the literature than the use of alternative measures such as per capita rent. As a result, according to the Stock and Yogo (2005) weak instrument tests, the instruments used for natural resource rent per gdp seems to be poor. The test results are available upon request.

19. This result could be explained by the fact that all variables apart from natural resource rent per capita are normalized with respect to GDP. One alternative is to estimate the model by standardizing all the variables by the population.

This postulate is unrealistic because the natural resource market and by extension natural resource revenues have a high level of variability due to uncertainty of supply and demand. As a result, the approach applied in most studies addressing the natural resource curse is a less effective one. Therefore, the PSTR is more appropriate since it is considered as linear heterogeneous panel model with coefficients that vary across individuals and over time.

Before starting the PSTR regression, it is necessary to check the integration order properties of the variables. We run the linear unit root test of Im et al. (2003) (IPS (2003)). The results presented in Table 3.8, confirm that all variables are stationary (e. g. all variables are I (0) processes). Thus, in line with González et al. (2004), the testing strategy is a step by step procedure. First, we test for linearity: in the case that the null hypothesis is not rejected, the testing procedure should be stopped and a different transition variable should be tested. On the opposite, if the null hypothesis of linearity is rejected, then the next step is to test the non-remaining linearity i.e. testing the number of regimes. Lastly, we proceed to the estimation of parameters. Since previous studies have documented that the Fisher-version of the test has better size properties in small samples than the asymptotic  $\chi^2$  based statistic (Dijk et al., 2002), we determine the number of transition regimes ( $r^*$ ) based on the Fisher-version statistics (in all cases considered in this paper, the *LM* test gives the same the number of transition regimes). The results of the linearity test are reported in Table 3.7 in appendix. They show that the linearity hypothesis is strongly rejected for the threshold variable. Determining the number of transition functions required to capture all non-linearity will be necessary. The null hypothesis of no remaining non-linearity is not rejected for the threshold variable. As such, only one transition function is required. Therefore, the coefficients fluctuate between a low and a high regime of rent volatility delimited by a threshold.

The following step is the parameters estimation. Table 3.2 reports the result of the PSTR estimation. As in logit or probit models, the value of the estimated parameters is not directly interpretable, but their signs are (Fouquau et al., 2008).<sup>20</sup> So, a negative sign (a positive sign respectively) of the parameter  $\beta$  means that an increase of the transition variable involves a decrease (increase respectively) of the resource rent-growth coefficient. To identify the channel(s) via which GDP per capita growth can be negatively impacted by rent volatility, we follow Beck et al. (2003) in con-

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20. It is important to note that the impact of NRA in a PSTR can be different from the estimated parameters for extreme regimes, i.e. parameters  $\alpha_1$  and  $\alpha'_1$ . As illustrated by equation (6), these parameters do not directly correspond to the NRA parameter. Parameter  $\alpha_1$  corresponds to the NRA coefficient only if the transition function  $g(VNRA_{it}, \gamma, \delta)$  tends towards 0. The sum of the  $\alpha_1$  and  $\alpha'_1$  parameters corresponds to the NRA coefficient only if the transition function  $g(VNRA_{it}, \gamma, \delta)$  tends towards 1. Between these two extremes, the NRA coefficient is defined as a weighted average of parameters  $\alpha_1$  and  $\alpha'_1$ . Therefore, it is generally difficult to directly interpret the values of these parameters that correspond to extreme situations

Table 3.2: Results of the PSTR model

Dependent variable: GDP growth per capita		
Model	Model A	Model B
Threshold variable	Rent volatility	Lag of Rent volatility
Initial GDP	-0.015*** (-8.12)	-0.013*** (-7.94)
FD	-0.040*** (-28.58)	-0.039*** (-28.95)
Trade openness	0.004* (1.73)	0.005** (2.07)
Corruption	-0.317*** (-8.30)	-0.275*** (-6.36)
VGDP	-0.310*** (-19.33)	-0.312*** (-20.42)
NRA	0.082*** (4.88)	0.062*** (3.27)
Investment	0.162*** (20.18)	0.169*** (21.12)
Human capital	0.928*** (5.36)	0.884*** (4.18)
Government stability	0.240*** (12.66)	0.249*** (12.67)
NRA*g	-0.215*** (-12.55)	-0.190*** (-9.83)
Investment*g	-0.629*** (-48.57)	-0.627*** (-46.59)
Human capital*g	-1.027*** (-6.42)	-1.085*** (-6.80)
Government stability*g	-0.023 (-0.52)	-0.008 (-0.16)
$\gamma$	2.92	2.94
$\delta$	1.98	1.99

Note: T-statistics are in (); \*, \*\* and \*\*\* refer to the 10%, 5% and 1% significance levels, respectively. Moreover, Model B uses lags for all the variables (threshold and independent variables). The vector parameters  $\beta$  ( $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ ) and  $\beta'$  ( $\alpha'_1, \alpha'_2, \alpha'_3, \alpha'_4$ ) correspond to the estimated vector parameters for extreme regimes i.e.  $\beta$  represents vector coefficients when the transition function  $g(VNRA_{it}, \gamma, \delta)$  tends towards 0 and the sum of  $\beta$  and  $\beta'$  represents vector of coefficients when the transition function tends towards 1.

Table 3.3: Individual estimated impact

Country	$\bar{\beta}_{NRA}$	$\bar{\beta}_{INV}$	$\bar{\beta}_{HCI}$	Country	$\bar{\beta}_{NRA}$	$\bar{\beta}_{INV}$	$\bar{\beta}_{HCI}$
Albania	0,066	0,114	0,851	Japan	0,082	0,160	0,924
Algeria	-0,096	-0,359	0,078	Jordan	0,055	0,083	0,799
Australia	0,048	0,062	0,765	Kazakhstan	-0,126	-0,446	-0,066
Austria	0,081	0,159	0,924	Kenya	0,075	0,141	0,895
Bahrain	0,045	0,053	0,750	Madagascar	0,053	0,078	0,790
Bangladesh	0,081	0,158	0,922	Malawi	-0,001	-0,083	0,529
Belgium	0,082	0,160	0,924	Malaysia	-0,018	-0,130	0,451
Bolivia	-0,021	-0,140	0,434	Mexico	0,049	0,064	0,768
Botswana	-0,017	-0,129	0,453	Morocco	0,055	0,083	0,798
Brazil	0,077	0,146	0,902	Netherlands	0,081	0,158	0,922
Bulgaria	0,079	0,154	0,915	New Zealand	0,080	0,156	0,919
Burkina Faso	-0,020	-0,136	0,441	Niger	0,027	-0,001	0,663
Cameroon	-0,056	-0,242	0,269	Norway	0,014	-0,037	0,603
Canada	0,078	0,148	0,906	Pakistan	0,081	0,157	0,920
Chile	-0,025	-0,151	0,418	Panama	0,081	0,159	0,924
China	0,024	-0,010	0,647	Paraguay	0,081	0,158	0,921
Colombia	0,051	0,070	0,778	Peru	-0,024	-0,148	0,421
Costa Rica	0,080	0,157	0,919	Philippines	0,076	0,144	0,898
Croatia	0,081	0,159	0,923	Poland	0,080	0,156	0,919
Cyprus	0,082	0,160	0,924	Portugal	0,081	0,159	0,924
Czechia	0,081	0,158	0,921	Republic of Korea	0,082	0,160	0,924
Côte d'Ivoire	0,058	0,091	0,813	Romania	0,077	0,146	0,902
Congo, Dem. Rep.	-0,114	-0,413	-0,011	Russian Federation	-0,011	-0,112	0,481
Denmark	0,081	0,157	0,921	Saudi Arabia	-0,125	-0,444	-0,062
Dominican Republic	0,052	0,074	0,785	Senegal	0,079	0,153	0,913
Ecuador	-0,082	-0,320	0,141	Slovakia	0,081	0,159	0,924
Egypt	-0,053	-0,233	0,283	Slovenia	0,081	0,159	0,924
El Salvador	0,081	0,159	0,923	South Africa	0,025	-0,006	0,654
Estonia	0,080	0,154	0,915	Spain	0,082	0,160	0,924
Finland	0,081	0,159	0,924	Sri Lanka	0,081	0,159	0,924
France	0,082	0,160	0,924	Sweden	0,081	0,159	0,923
Gabon	-0,130	-0,458	-0,084	Switzerland	0,082	0,160	0,924
Germany	0,081	0,160	0,924	Thailand	0,080	0,156	0,919
Greece	0,081	0,159	0,924	Togo	-0,023	-0,145	0,426
Guatemala	0,081	0,157	0,920	Tunisia	0,052	0,072	0,782
Honduras	0,079	0,152	0,911	Turkey	0,081	0,159	0,924
Hungary	0,081	0,159	0,923	Uganda	-0,068	-0,278	0,209
India	0,071	0,129	0,874	Ukraine	0,040	0,039	0,727
Indonesia	0,014	-0,039	0,601	United Arab Emirates	-0,130	-0,459	-0,086
Ireland	0,081	0,159	0,923	United Kingdom	0,081	0,157	0,921
Israel	0,081	0,159	0,924	United Republic of Tanzania	0,029	0,006	0,673
Italy	0,082	0,160	0,924	United States of America	0,081	0,157	0,921
Jamaica	0,051	0,071	0,780	Uruguay	0,081	0,158	0,922

Note: For each country, the average  $\bar{\beta}$  effect of each regime dependent variable on economic growth is reported.



sidering three potential channels that are widely recognized in the literature: investment, human capital (education) and the quality of institutions. Both the importance of these channels and the arguments why they may be potential drivers of growth curbing in resource rich countries are extensively discussed in Gylfason (2006). Turning to our variables of interest, Model A presents the estimation results of the conditional impact of natural resource rent, investment, human capital and institution on economic growth according to the level of rent volatility. The marginal impact of these variables is positive as long as the level of rent volatility is below the threshold of 1.97. Conversely, when the estimated threshold is reached, there is clear evidence of conditional resource curse through the impact of resource rent, investment and human capital. Indeed, at a low level of volatility, resource rent (0.082) and investment (0.162) have a positive impact on growth but it turns negative for both in the regime of high rent volatility (-0.215 and -0.629). Therefore, these results confirm our previous findings; a higher volatility turns the resource blessing into resource curse which confirms the major role of the volatility channel. There is a strong evidence that investment is an important channel by which rent volatility affects GDP per capita growth. This finding is in line with the claims of Papyrakis and Gerlagh (2004) and Gylfason (2006). This result may be attributed in part to the fact that economic agents tend to save less in commodity abundant countries because they perceive revenues from primary commodity exports as a permanent flow of future income. An additional relevant factor in these economies may be the uncertainty brought about by the volatility of resource rents in these economies, which can impede the accumulation of physical capital by risk-averse investors. As noted by Catão and Kapur (2006) and ?, terms-of-trade volatility affects both capital accumulation and growth negatively because it increases the country's default risk and therefore increases its spreads and reduces its financing capacity. As well, there is evidence that human capital accumulation is another vector through which volatility affects growth. It has a positive impact (0,928) in the low rent volatility regime, it turns negative (-1,027) in the regime of high rent volatility. Indeed, the crowding-out effect of rent volatility on human capital might explain the curse of resource abundant countries induced either by the low level of educational spending or by the weakness of the educational system (Gylfason, 2001). The prosperity of resource based industries can lead to an increase in the opportunity cost of receiving education and the decline in the household's desire to obtain human capital causing declining in human capital accumulation. A final possible mechanism for this observation is that uncertainty generally widens income inequality and results in tight credit constraints for low net worth households. However, since households pay for their own education, greater volatility leads to a reduction in investment in human capital and therefore to a decline in economic growth. This decline due

to the crowding out of human capital and investment in resource-rich and/or volatile economies is also consistent with the literature (?). Finally, the institutional quality impacts positively the growth at low level of volatility and becomes insignificant at high level of volatility. This means that the higher the level of volatility, the lower the sensitivity of economic growth to institutional quality. In the same way, the lower the level of volatility is, the greater the impact of institutional quality on growth.

Table 3.3 reports for each country the average estimated coefficients attributed to each regime dependent variable. The results show that the average estimated impacts of regime dependent variable on GDP growth are quite different from one country to another and depend negatively on the level of natural resource rent volatility. This finding is clearly illustrated by Fig 3.3, Fig 3.4 and Fig 3.5 that displays the country average impact of resource rent, investment and human capital against the country average level of natural resource rent volatility, respectively. We should also notice that the transition between the growth enhancing regime and the natural resource curse regime takes place in a smooth fashion as illustrated by the low level of the speed parameter ( $\gamma = 2.92$ , see Table 3.2).

In addition to these figures, quantifying the overall net impact of volatility on the GDP loss seems essential. One way to do this is to assess what happens for GDP growth when volatility increases, all other things being equal. The first step involves obtaining the average over time for each country, of the estimated coefficients associated with the explanatory variables that are function of the level of volatility (see Table 3.3). Then, in order to be able to conduct a *ceteris paribus* reasoning, we opt for a reference scenario where all countries of the sample have the same levels of natural resources, investment and human capital. In the reference scenario, the levels of natural resources, investment and human capital are the averages of the corresponding variables over time and among countries. Finally, we compute the predicted value of GDP growth rate in the reference scenario for each country. The differences in the predicted values of GDP growth rates will only reflect the differences between countries's natural-resource volatilities. We find huge differences in growth rates between the countries characterized by low natural-resource volatilities, such as France, USA, Switzerland and Japan, and those characterized by high natural-resource volatilities, such as Saudi Arabia and United Arab Emirates, *ceteris paribus*. The GDP growth loss may reach 17 percentage-point per year. Figure 3.6 shows the impact of volatility increase on output loss in percentage-point reasoning. Volatility is represented on the horizontal axis while GDP growth loss on the vertical axis.

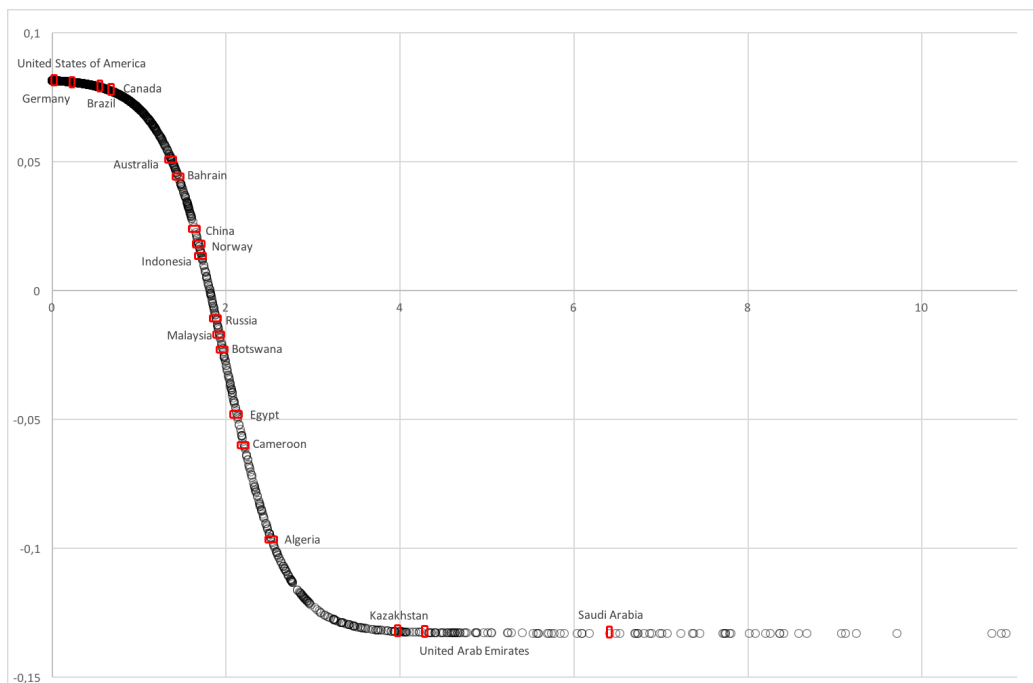


Figure 3.3: Estimated impact of natural resource rent on GDP/Capita growth.

Note: The figure represents estimated impact of natural resource rent on GDP/Capita growth using the historical value of the transition function (volatility of natural resource rent). Each circle represents an observation.

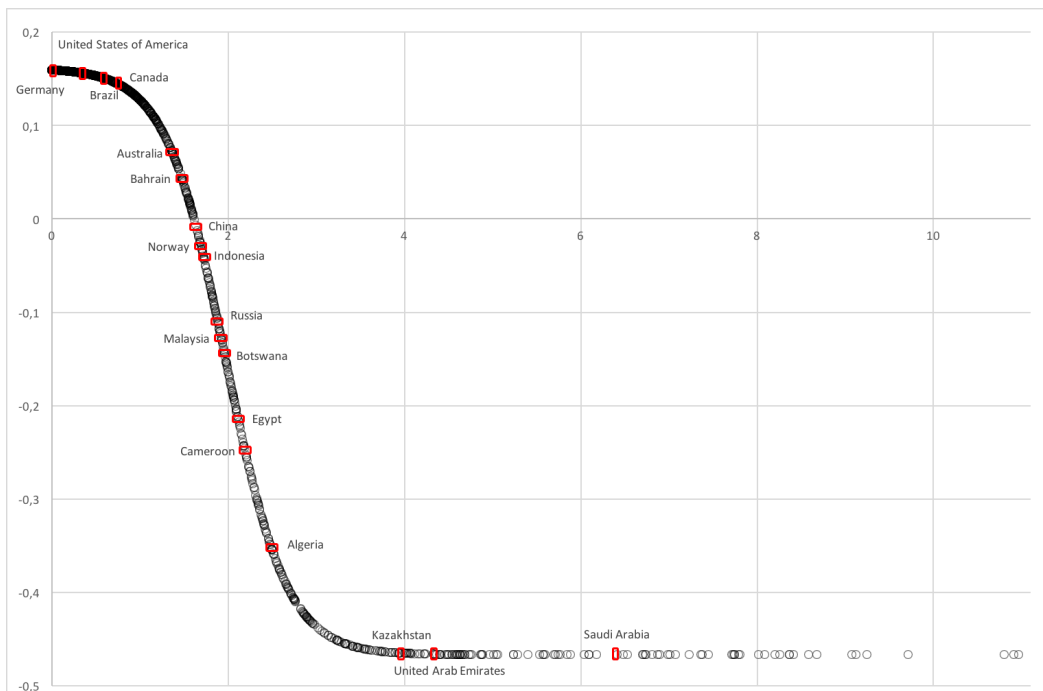


Figure 3.4: Estimated impact of investment on GDP/Capita growth.

Note: The figure represents estimated impact of investment on GDP/Capita growth using the historical value of the transition function (volatility of natural resource rent). Each circle represents an observation.

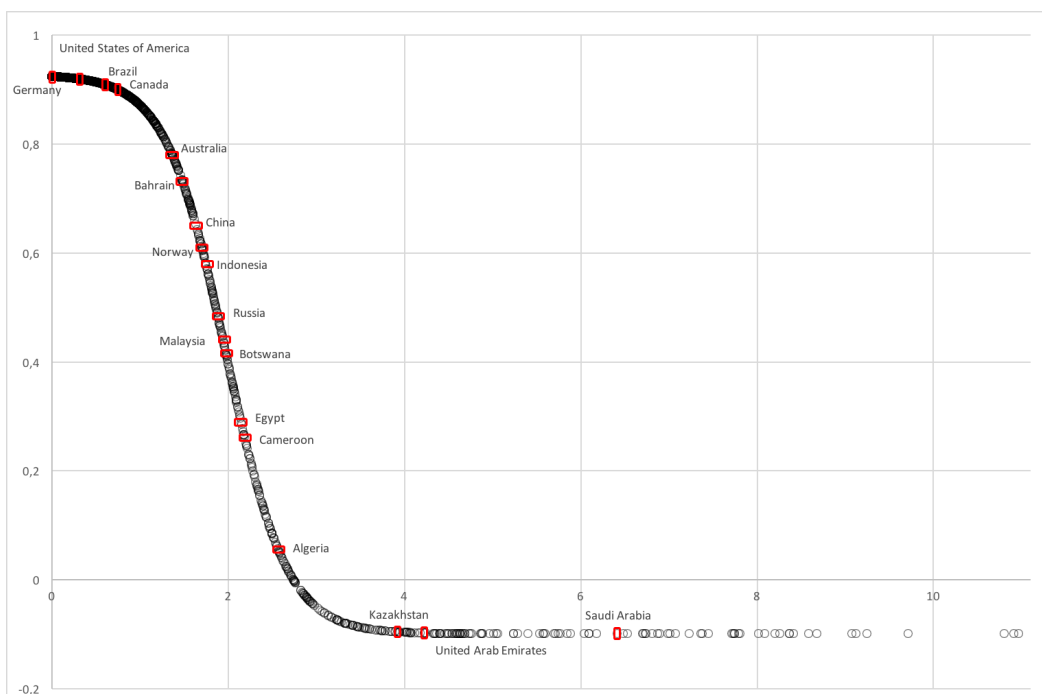


Figure 3.5: Estimated impact of human capital on GDP/Capita growth.  
 Note: The figure represents estimated impact of human capital on GDP/Capita growth using the historical value of the transition function (volatility of natural resource rent). Each circle represents an observation.

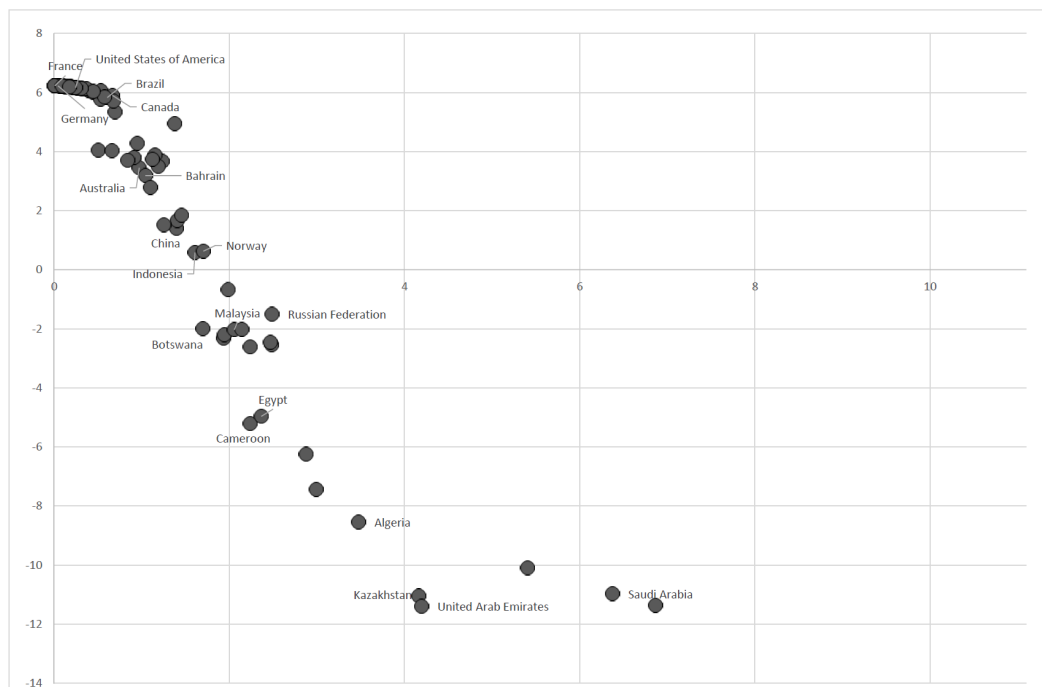


Figure 3.6: Estimated impact of volatility on GDP/Capita growth.  
 Note: The figure represents estimated impact of volatility on GDP/Capita growth using the historical value of the transition function (volatility of natural resource rent). Each circle represents average impact for each country.

Furthermore, the coefficients of the control variables in all the regressions generally have the expected signs, or being statistically insignificant. Financial development is negatively related to growth. This is much in line with the recent empirical research that contradicts the traditional findings. Indeed, it is reasonable to assume that an increase in financial development promotes growth if the level of development of the financial system is low, but becomes negative in countries with advanced financial sectors. Demirgüç-Kunt and Huizinga (2010) illustrate that banks have gradually steered away from their traditional intermediation activities during the last decades. In the 1990s and the 2000s, non-interest incomes of banks in countries with advanced financial markets experienced a substantial increase, particularly via trading of mortgage-backed securities. A higher level of financial depth provides the potential to fund a larger number of investment projects. However, there may be a point at which the remaining investment projects are less profitable than the development of new business fields. This particularly holds if the financial sector grows at a higher rate than the number of promising investment opportunities. However, the shift in banking activities observable over the past decades has led to higher inflation rates and an increasing vulnerability of banks to economic crises without triggering any growth stimuli (Demirgüç-Kunt and Huizinga, 2010). Trade openness and corruption has the expected sign and significant at five percent level. These findings confirm the results of the within estimation strategy.

In order to check the robustness of our results, we also run the estimations using the lag of both natural resource rent volatility and independent variables. The results presented in Model B of Table 3.2 are consistent with the previous conclusions. Similarly to fixed effect analysis, the validity of the PSTR results is tested by using a measure of natural resource rent per capita rather than natural resource rent per GDP. The results of linearity test and PSTR results are reported in Table 3.8 and 3.11, respectively. In the regime of low resource rent volatility (below 2.67 threshold), natural resource rent per capita improves economic performance. However, it has the opposite effect for high regime of natural resource rent volatility. The main findings regarding the impact of natural resource rent volatility on investment, human capital and institutional quality hold and are thus robust to the change of the natural resource endowment measure. We also consider other variables such as inflation, population growth rate and exchange rate. Both inflation and population growth rate impact negatively GDP per capita growth rate, as predicted by the theory. The exchange rate turns out to be not significant at five percent level. Overall the results are robust to adding further control variables (see Table 3.13).

## 3.6 Conclusion

This paper investigates the resource curse paradox using two different methods. We first test for the resource curse hypothesis relying on standard fixed-effect regressions which imperfectly take into account the conditional impact of rent volatility. We then use a more flexible econometric approach: a panel smooth transition regression model. This model better addresses the conditional nature of the resource curse. Although the traditional resource curse hypothesis predicts a negative effect of resource abundance on growth, our results are somewhat different and show that resource abundance, proxied by the ratio of natural-resource rent over GDP, has a positive impact on output growth. We however find strong evidence that resource rent volatility impacts negatively output growth. We show that GDP growth loss may reach 17 percentage-points per year for countries suffering from the highest natural-resource rent volatility such as Saudi Arabia and the United Arab Emirates compared with countries with low natural-resource rent volatility (such as France, USA, Switzerland and Japan), all things being equal. Consequently, we claim that volatility of natural resource rent, rather than abundance as such, that drives the resource curse paradox. Our results corroborate previous findings in the literature on the conditional natural resource curse. The latter asserts that natural resources are growth-enhancing even if they have adverse effects through various transmission mechanisms. Indeed, we show that the marginal impact of natural resource rent, investment, human capital and institutional quality on growth is a decreasing function of resource rent volatility. Our results emphasize the importance of volatility in explaining the under-performance of resource abundant countries.

More importantly, as several channels may lead to harmful effects, it is essential that each resource rich country implements specific economic policies to limit these negative impacts. There are several economics policies implemented to counteract the negative effects of natural resource abundance such as sovereign wealth funds (SWF), stabilization funds, export diversification and developed financial systems. We find evidence that countries with developed financial systems can offset some of the negative impacts of natural-resource rent volatility. Consequently, resource abundance may be a blessing when policies enhancing growth, welfare and financial development are implemented.

### 3.7 Appendix

Table 3.4: List of countries (103)

Developing countries		Developed countries
Albania	Kuwait	Australia
Algeria	Madagascar	Austria
Angola	Malawi	Belgium
Azerbaijan	Malaysia	Canada
Bahrain	Mali	Cyprus
Bangladesh	Mexico	Czechia
Bolivia	Morocco	Denmark
Botswana	Namibia	Estonia
Brazil	Nicaragua	Finland
Bulgaria	Niger	France
Burkina Faso	Nigeria	Germany
Cameroon	Oman	Greece
Chile	Pakistan	Ireland
China	Panama	Israel
Colombia	Paraguay	Italy
Congo	Peru	Japan
Costa Rica	Philippines	Latvia
Croatia	Poland	Lithuania
Côte d'Ivoire	Romania	Netherlands
Congo, Dem. Rep.	Russian Federation	New Zealand
Dominican Republic	Saudi Arabia	Norway
Ecuador	Senegal	Portugal
Egypt	South Africa	Republic of Korea
El Salvador	Sri Lanka	Slovakia
Gabon	Sudan	Slovenia
Gambia	Syrian Arab Republic	Spain
Ghana	Thailand	Sweden
Guatemala	Togo	Switzerland
Honduras	Tunisia	United States of America
Hungary	Turkey	
India	Uganda	
Indonesia	Ukraine	
Iran, Islamic Rep.	United Arab Emirates	
Iraq	United Kingdom	
Jamaica	United Republic of Tanzania	
Kazakhstan	Venezuela	
Kenya	VietNam	

Table 3.5: List of variables and sources

Variable	Definition and Construction	Source
GDP per capita growth	Log difference of real GDP (constant 2010 US\$) per capita averaged over the years $t - 4$ to $t$ .	
Volatility of GDP per capita growth	Standard deviation of GDP per capita growth over the years $t - 4$ to $t$ .	
Natural resources rents (% of GDP)	Natural resources as a share of GDP, averaged over the years $t - 4$ to $t$ . Natural resources rents are the sum of oil rents, natural gas rents, coal rents (hard and soft), mineral rents, and forest rents.	
Volatility of Natural resources rents (% of GDP)	Standard deviation of Natural resources rents (% of GDP) over the years $t - 4$ to $t$ .	Authors calculation using data from the World Bank (2010) WDI.
Trade Openness	Trade is the sum of exports and imports of goods and services measured as a share of GDP and averaged over the years $t - 4$ to $t$ .	
Fuel exports	Fuel exports as share of good and services, averaged over the years $t - 4$ to $t$ .	
Investment	Gross fixed capital formation (formerly gross domestic fixed investment) as share of GDP, averaged over the years $t - 4$ to $t$ .	
Private credit (% of GDP)	Private credit by banks and other financial institutions as share of GDP, averaged over the years $t - 4$ to $t$ .	Authors calculation using data from the Financial development 2018.
Government Stability	Government Stability is an assessment both of the government's ability to carry out its declared program(s), and its ability to stay in office averaged over the years $t - 4$ to $t$ .	Authors calculation using data from the International country risk guide (Political Risk Services (2008)).
Corruption	This is an assessment of corruption within the political system averaged over the years $t - 4$ to $t$ .	
Human Capital	Human capital index, based on years of schooling and returns to education, averaged over the years $t - 4$ to $t$ .	Authors calculation using data from the Penn World Table 9.0.



Table 3.6: Fixed effect estimation results

Dependent variable: GDP growth rate per capita					
Method	1	2	3	4	5
	FE	FE	FE	FE	FE
Initial GDP	-0.017*** (-4.92)	-0.015*** (-4.86)	-0.015*** (-4.47)	-0.017*** (-5.28)	-0.014*** (-3.35)
NRA	-0.001 (0.53)	0.007*** (3.78)	0.007*** (3.73)	0.003** (2.08)	0.006*** (3.57)
VNRA		-0.018*** (-5.82)	-0.020*** (-4.20)	-0.019** (-2.55)	-0.017*** (-4.53)
VGDP	-0.303*** (-6.41)	-0.277*** (-6.01)	-0.277*** (-5.99)	-0.277*** (-6.00)	-0.257*** (-5.73)
FD	-0.030*** (-5.90)	-0.031*** (-6.33)	-0.031*** (-6.29)	-0.029*** (-5.73)	-0.020*** (-3.65)
Government Stability	0.253*** (2.35)	0.267*** (2.55)	0.277*** (2.64)	0.271*** (2.69)	0.281*** (2.68)
Corruption	-0.502*** (-3.35)	-0.496*** (-3.24)	-0.486*** (-3.03)	-0.475*** (-3.23)	-0.460*** (-2.62)
Investment	0.052*** (2.61)	0.063*** (3.25)	0.063*** (3.24)	0.063*** (3.23)	0.049 (0.90)
Humain capital	-0.794 (-0.81)	-1.028 (-1.09)	-1.028 (-1.09)	-1.217 (-1.26)	-2.75 (-0.89)
Trade openness	0.014** (2.16)	0.018*** (2.90)	0.018*** (2.89)	0.018*** (2.90)	0.021*** (2.27)
Exchange rate					0.000 (-0.85)
Inflation					-0.001*** (-2.63)
Pop growth					-0.362* (-1.96)
NRA*VNRA			-0.004 (-1.03)	-0.000 (-0.09)	-0.002 (-0.77)
VNRA*FD				-0.000 (-1.10)	0.003 (1.41)
Constant	4.56 (1.34)	5.36* (1.81)	5.35 (1.40)	4.61 (1.29)	6.61** (2.18)
Observations	635	635	635	635	618
Number of countries	102	102	102	102	102
Time fixed effect	Yes	Yes	Yes	Yes	Yes

Note: T-statistics are in (); \*, \*\* and \*\*\* refer to the 10%, 5% and 1% significance levels, respectively. This table reports the results when using a measure of natural resource rent per capita instead of natural resource rent per GDP.

Table 3.7: IV-Fixed effect estimation results (regressions 1-5)

Dependent variable: GDP growth per capita					
Method	1 FE	2 FE-IV	3 FE-IV	4 FE-IV	5 FE-IV
Initial level of GDP	-0.011*** (-3.34)	-0.012*** (-3.69)	-0.010** (-3.41)	-0.010** (-3.56)	-0.012** (-2.79)
NRA	0.174** (3.58)	0.181*** (3.83)	0.228*** (4.11)	0.218*** (3.84)	-0.073 (-0.30)
NRD	-0.021*** (-2.16)	-0.012 (-0.22)	0.026 (-0.40)	0.026 (-0.47)	
VNRA	-0.294** -2.26	-0.313** (-2.12)	-0.006 (-1.10)	-0.128 (-1.05)	-0.608** (-2.49)
VGDP	-0.256*** (-4.54)	-0.238*** (-3.92)	-0.235*** (-3.95)	-0.225*** (-3.66)	-0.242*** (-4.24)
FD	-0.014*** (-2.72)	-0.012*** (-2.55)	-0.014*** (-2.91)	-0.017*** (-3.70)	-0.023*** (-3.39)
Government Stability	0.235*** (2.86)	0.235*** (2.65)	0.248*** (2.87)	0.246*** (2.88)	0.303*** (3.00)
Corruption	-0.343** (-2.17)	-0.302** (-2.20)	-0.303** (-2.19)	-0.333** (-2.27)	-0.502*** (-2.91)
Investment	0.068* (1.88)	0.063* (1.78)	0.064* (1.79)	0.062** (1.99)	0.054 (1.45)
Human capital	-1.20 (-1.33)	-1.51 (-1.52)	-1.19 (-1.14)	-1.15 (-0.68)	-2.97 (-1.44)
Trade openness	0.012 (1.48)				
Exchange rate	-0.0001* (-1.96)	-0.0001 (-1.12)	-0.0001 (-1.03)	-0.0001 (-1.32)	-0.0001 (-0.96)
Inflation	-0.0009*** (-3.57)	-0.0008** (-2.36)	-0.0009** (-2.40)	-0.0008** (-2.20)	-0.0013** (-2.18)
Pop growth	-0.482** (-3.05)	-0.555** (-3.42)	-0.489** (-2.86)	-0.504** (-3.04)	-0.60*** (-3.46)
NRA*VNRA				-0.012** (-2.03)	0.011 (0.81)
VNRA*FD				0.005* (1.88)	0.013** 2.31
Constant	10.82** (3.14)	3.25 (1.63)	4.51 (1.52)	3.86 (1.34)	4.11 (1.44)
Observations	590	580	580	580	606
Number of countries	101	101	102	102	102
Time fixed effect	Yes	Yes	Yes	Yes	Yes

Note: T-statistics are in (); \*, \*\* and \*\*\* refer to the 10%, 5% and 1% significance levels, respectively. Columns 2 to 4 present the results of FE-IV by considering NRD as endogenous, while column 5 presents the results of FE-IV by considering the variable NRA as endogenous. NRD and NRA represent natural resource dependence and natural resource abundance variables, respectively.

Table 3.8: The panel unit root test results

Test	IPS	
	Statistic	P-value
GDP growth	-3.658***	(0.0001)
NRA	-2.461 ***	(0.0069)
VNRA	-10.784***	(0.0000)
VGDP	-4.531***	(0.0000)
FD	-3.697***	(0.0001)
Government stability	-5.575***	(0.0000)
Corruption	-6.008***	(0.0000)
Investment	-6.202***	(0.0000)
Human capital	-25.164***	(0.0000)
Trade openness	-4.906***	(0.0000)
Exchange rate	-3.738***	(0.0001)
Inflation	-47.322***	(0.0000)
Pop growth	-4.763***	(0.0000)

Note: P-value are in (); \*, \*\* and \*\*\* refer to the 10%, 5% and 1% significance levels, respectively.

The Lag selection (automatic) is based on Schwarz information criterion (SIC).

Table 3.9: Linearity and no-remaining linearity tests for Model A and B

Threshold variable	Rent volatility	Lag of Rent volatility
$r^*$	1	1
$H_0 : r = 0$ vs $H_1 : r = 1$		
Wald test ( $LM$ )	767.077 (0.000)	765.978 (0.000)
Fisher test ( $LM_f$ )	916.115 (0.000)	955.955 (0.000)
$H_0 : r = 1$ vs $H_1 : r = 2$		
Wald test ( $LM$ )	2.095 (0.078)	0.603 (0.660)
Fisher test ( $LM_f$ )	8.982 (0.061)	2.783 (0.595)
Location parameter $\delta$	1.976	1.995
Smooth parameter $\gamma$	2.922	2.941

Note: Under  $H_0$ ,  $LM$  and  $LRT$  have an asymptotic  $\chi^2(4)$ ,  $LMF$  has an asymptotic  $F(4, TN - N - (r + 1))$  where  $N$  is the number of individuals,  $T$  the number of periods and  $r$  the number of threshold under  $H_0$ . For tests statistics, p-value are in parentheses. The test strategy is as follows: first we test the linear model ( $r = 0$ ) against a model with one threshold ( $r = 1$ ). If the null hypothesis is rejected, the single threshold is tested against a double threshold ( $r = 2$ ). This latter part tests the no-remaining linearity. For each one of the above model, we accept the hypothesis of one threshold and two regimes. The p-values are reported in parentheses.

Table 3.10: Linearity and no-remaining linearity tests for Model C and D

Threshold variable	Rent volatility	Lag of Rent volatility
$r^*$	1	1
$H_0 : r = 0$ vs $H_1 : r = 1$		
Wald test ( $LM$ )	84.084 (0.000)	85.737 (0.000)
Fisher test ( $LM_f$ )	54.184 (0.000)	57.701 (0.000)
$H_0 : r = 1$ vs $H_1 : r = 2$		
Wald test ( $LM$ )	0.975 (0.419)	0.985 (0.414)
Fisher test ( $LM_f$ )	4.416 (0.353)	5.009 (0.286)
Location parameter $\delta$	5.731	5.807
Smooth parameter $\gamma$	2.676	3.603

Note: Under  $H_0$ ,  $LM$  and  $LRT$  have an asymptotic  $\chi^2(4)$ ,  $LMF$  has an asymptotic  $F(4, TN - N - (r + 1))$  where  $N$  is the number of individuals,  $T$  the number of periods and  $r$  the number of threshold under  $H_0$ . For tests statistics, p-value are in parentheses. The test strategy is as follows: first we test the linear model ( $r = 0$ ) against a model with one threshold ( $r = 1$ ). If the null hypothesis is rejected, the single threshold is tested against a double threshold ( $r = 2$ ). This latter part tests the no-remaining linearity. For each one of the above model, we accept the hypothesis of one threshold and two regimes. The p-values are reported in parentheses.

Table 3.11: Results of the PSTR model

Dependent variable: GDP growth per capita		
Model	Model C	Model D
Threshold variable	Rent volatility	Lag of Rent volatility
Initial GDP	-0.013*** (-12.42)	-0.012*** (-11.74)
FD	-0.039*** (-26.82)	-0.040 (-26.39)
Trade openness	0.003 (1.48)	0.002 (1.03)
Corruption	-0.283*** (-6.76)	-0.404*** (-9.56)
VGDP	-0.051*** (-3.26)	-0.034** (-2.35)
NRA	0.007*** (5.95)	0.007*** (4.91)
Investment	0.064*** (8.01)	0.078*** (10.31)
Human capital	0.565*** (2.73)	0.732*** (3.28)
Government stability	0.433*** (24.19)	0.442*** (23.69)
NRA*g	-0.026*** (-21.06)	-0.024*** (-18.79)
Investment*g	-0.134*** (-4.34)	-0.103*** (-4.87)
Human capital*g	-0.855** (-2.22)	-1.510*** (-3.70)
Government stability*g	0.026 (0.25)	0.123 (1.03)
$\gamma$	2.67	3.60
$\delta$	5.73	5.80

Note: Note: T-statistics are in (); \*, \*\* and \*\*\* refer to the 10%, 5% and 1% significance levels, respectively. Moreover, Model D uses lags for all the variables (threshold and independent variables). This table reports the results when using a measure of natural resource rent per capita instead of natural resource rent per GDP. The vector parameters  $\beta$  ( $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ ) and  $\beta'$  ( $\alpha'_1, \alpha'_2, \alpha'_3, \alpha'_4$ ) correspond to the estimated vector parameters for extreme regimes i.e.  $\beta$  represents coefficients when the transition function  $g(VNRA_{it}, \gamma, \delta)$  tends towards 0 and the sum of  $\beta$  and  $\beta'$  represents vector of coefficients when the transition function tends towards 1.

Table 3.12: Correlation between usual proxies of institutional quality and financial development and trade openness

Variables	Government Stability	Law and Order	Democratic Accountability	Bureaucracy Quality	Financial Development	Trade Openness
Government stability	1					
Law and Order	0.42	1				
Democratic Accountability	0.14	0.49	1			
Bureaucracy Quality	0.27	0.70	0.63	1		
Financial Development	0.14	0.49	0.41	0.51	1	
Trade Openness	0.20	0.26	0.06	0.22	0.35	1

Table 3.13: Results of the PSTR model

Dependent variable: GDP growth per capita		
Model	Model E	Model F
Natural resource variable	<i>(Rent/Gdp)</i>	<i>(Rent/Pop)</i>
Initial GDP	-0.013*** (-7.12)	-0.011*** (-6.94)
FD	-0.038*** (-25.78)	-0.038*** (-25.45)
Trade openness	0.004* (1.83)	0.005** (2.20)
Corruption	-0.302*** (-6.30)	-0.275*** (-8.36)
VGDP	-0.330*** (-17.43)	-0.045*** (-22.27)
Exchange rate	0.0002 (1.24)	0.0001 (1.10)
Inflation	-0.001*** (-12.80)	-0.002*** (-20.37)
Pop growth	-0.420*** (-9.45)	-0.416*** (-13.13)
NRA	0.081*** (5.89)	0.009*** (7.05)
Investment	0.161*** (16.78)	0.080*** (16.12)
Human capital	0.932*** (7.36)	0.560*** (4.32)
Government stability	0.240*** (15.06)	0.249*** (13.87)
NRA*g	-0.225*** (-17.95)	-0.028*** (-12.33)
Investment*g	-0.632*** (-30.57)	-0.110*** (-9.89)
Human capital*g	-1.089*** (-8.26)	-0.850*** (-3.20)
Government stability*g	-0.019 (-1.12)	-0.002 (-1.16)
$\gamma$	2.91	2.55
$\delta$	1.99	2.00

Note: T-statistics are in (); \*, \*\* and \*\*\* refer to the 10%, 5% and 1% significance levels, respectively. Model E uses natural resource rent per Gdp. Model F uses natural resource rent per capita. The vector parameters  $\beta$  ( $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ ) and  $\beta'$  ( $\alpha'_1, \alpha'_2, \alpha'_3, \alpha'_4$ ) correspond to the estimated vector parameters for extreme regimes i.e.  $\beta$  represents vector coefficients when the transition function  $g(VNRA_{it}, \gamma, \delta)$  tends towards 0 and the sum of  $\beta$  and  $\beta'$  represents vector of coefficients when the transition function tends towards 1.

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## Abstract

This thesis examines how societies use and sustain the natural resources that fundamentally shape human well-being, the environment and the economy. The links between economic prosperity, resources and environmental preservation are complex and diverse. This implies that, if all dimensions are not taken into account in public policy making, any progress in achieving objectives in these areas can be hindered by undesirable outcomes. An key issue in development studies is how natural resource wealth affects long-term economic growth. In order to address this question, the first chapter examines the impact of non-conventional resource development on the US manufacturing sector over the period 1997-2013. In the same vein, chapter 3 examines the impact of abundant natural resources on the economy by exploiting the volatility channel of natural resources rent on a panel of 103 countries between 1985-2014. Moreover, the extraction and processing of natural resources are often energy-intensive activities that involve large-scale ecosystem alterations. Chapter 2 of the thesis investigates the impact of natural resource abundance on CO<sub>2</sub> intensity in developed countries over the period 1995-2014.

*Keywords : Natural resources, economic development, environmental policy, panel data.*

## Résumé

Cette thèse étudie la façon dont les sociétés utilisent et entretiennent/préservent les ressources naturelles qui façonnent fondamentalement le bien-être de l'humanité, l'environnement et l'économie. Les liens entre la prospérité économique, ressources et impacts environnementaux et la protection environnementale sont complexes et variés. Cela signifie que, si toutes ces dimensions ne sont pas prises en compte dans l'élaboration des politiques publiques, tout progrès dans la réalisation des ambitions dans ces domaines peut être entravé par des conséquences négatives. Une question importante dans les études sur le développement est de savoir comment la richesse en ressources naturelles affecte la croissance économique à long terme. Dans la perspective de répondre à cette question, le premier chapitre étudie l'impact de l'exploitation des ressources non-conventionnelles sur le secteur manufacturier des Etats-Unis sur la période 1997-2013. Dans la même perspective, le troisième chapitre étudie l'impact de l'abondance de ressources naturelles fossiles et minérales sur l'économie en exploitant le canal de la volatilité de la rente due aux ressources naturelles sur un panel de 103 pays entre 1985-2014. Par ailleurs, l'extraction et la transformation des ressources naturelles sont souvent des activités à forte intensité énergétique qui impliquent des modifications à grande échelle des écosystèmes. Le deuxième chapitre de la thèse étudie l'impact de l'abondance des ressources naturelles sur l'intensité en CO<sub>2</sub> dans les pays développés sur la période 1995-2014.

*Mots-clés : Ressources naturelles, développement économique, politique environnementale, données de panel.*