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# Fiscalité environnementale, dette publique et croissance économique : une analyse macroéconomique

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# Thèse de Doctorat

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## Fiscalité environnementale, dette publique et croissance économique: une analyse macroéconomique

### JURY

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## Introduction générale

La convention de Rio (1992), le protocole de Kyoto (1997), et l'accord de Paris (2015) sur le climat, reflètent une préoccupation internationale sur les questions d'environnement durant les trois dernières décennies. Cette préoccupation a donné aux politiques environnementales une place de plus en plus importante dans un grand nombre de pays autour du monde.

Les pays de l'Organisation de Coopération et de Développement Économiques (OCDE) ont montré un intérêt croissant à l'utilisation des taxes liées à l'environnement comme principal instrument dans leurs politiques environnementales (voir [OECD, 2006](#)). L'un des avantages de cet instrument est qu'il procure des recettes publiques qui peuvent être redistribuées. C'est l'une des raisons pour lesquelles la taxation peut être préférée au versement de subventions ou aux quotas d'émission.

Les revenus générés par ces impôts dans la zone de l'OCDE sont passés de 420.754 milliards US\$ en 1994 à 786.143 milliards US\$ en 2013<sup>1</sup>. Dans le même temps, plusieurs pays européens procèdent à une réforme dite "verte" de ces revenus. Ils utilisent les recettes de la fiscalité environnementale pour réduire d'autres taxes ou subventionner des activités de dépollution ou d'innovation en matière d'environnement ([European Environment Agency, 2011](#); [Withana et al., 2013, 2014](#)).

L'objectif principal des politiques fiscales environnementales est de réduire la pollution et les émissions de gaz à effet de serre, par conséquent, augmenter le bien-être de la société. Toutefois, cela peut avoir une influence négative sur la croissance économique, en particulier à court terme ([Siriwardana et al., 2011](#); [Wang et al., 2015](#)).

La façon dont la fiscalité environnementale affecte la croissance économique est une question centrale et controversée dans la littérature sur la croissance et l'environnement, ainsi que dans le débat politique concernant la conception des politiques environnementales.

Bien qu'il existe de nombreuses études théoriques qui ont répondu à cette question<sup>2</sup>, il n'y a pas de consensus sur la nature de l'impact de la fiscalité environnemental sur la croissance

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<sup>1</sup> Voir le site : [https://stats.oecd.org/Index.aspx?DataSetCode=ENV\\_ENVPOLICY](https://stats.oecd.org/Index.aspx?DataSetCode=ENV_ENVPOLICY)

<sup>2</sup> Initialement, la littérature s'est focalisée sur le problème de l'exploitation des ressources naturelles épuisables ([Nordhaus, 1973](#); [Solow, 1974](#); [Dasgupta and Heal, 1974](#)) ou les limites qu'imposent la pollution sur la croissance économique ([Keeler et al., 1972](#)).

économique à court et à long terme. Certaines études montrent un effet négatif ([Bovenberg and Heijdra, 1998](#); [Labandeira et al., 2004](#); [Siriwardana et al., 2011](#); [Wang et al., 2015](#)), alors que d'autres trouvent un impact positif ([Acemoglu et al., 2012](#); [Aloi and Tournemaine, 2011](#); [Chen et al., 2017](#); [Ewijk and Wijnbergen, 1994](#); [Gehrsitz, 2017](#); [Gradus and Smulders, 1993](#); [Hart, 2008](#); [Hattori, 2017](#); [Kim et al., 2017](#); [Mabahwi et al., 2014](#); [OECD, 2010](#); [Vellinga, 1999](#)).

Cette divergence dans les résultats est due aux hypothèses utilisées dans chaque modèle, en particulier sur le moteur de croissance considéré. Selon la théorie de la croissance endogène, il existe quatre moteurs principaux de la croissance économique à long terme : le capital physique ([Romer, 1986](#); [Rebelo, 1991](#)), le capital humain ([Lucas, 1988](#)), l'innovation ([Romer, 1990](#)), et le capital public ([Barro, 1990](#)). Les travaux qui ont conclu à un effet négatif supposent que le capital physique est le moteur unique de la croissance économique. Dans ce cas, les taxes imposées sur les émissions polluantes contribuent à augmenter les prix des combustibles fossiles. Cela réduirait la quantité des combustibles fossiles utilisée dans les processus de production. Ce qui se traduit par une baisse de la productivité du capital physique et ainsi la croissance économique. Les modèles qui ont montré un effet positif supposent qu'en plus du capital physique, le capital humain et/ou l'innovation sont des moteurs majeurs de la croissance économique. Dans ce cas, la diminution de la pollution grâce à la fiscalité environnementale améliore la santé publique et favorise la capacité d'apprentissage, renforçant l'accumulation du capital humain et donc la croissance économique. D'autre part, l'augmentation des prix des combustibles fossiles à cause de la fiscalité environnementale encourage les entreprises à investir dans les technologies propres et donc promouvoir la croissance économique à long terme.

Il est intéressant de noter que les études empiriques qui permettent de vérifier la validité de ces hypothèses au niveau macroéconomique sont rares. La rareté des études empiriques sur le sujet peut être expliquée par le manque de données structurées sur la fiscalité environnementale. Les données fournies par l'OCDE contiennent seulement les recettes générées par les taxes liées à l'environnement mais pas leurs taux. En plus, les données les plus anciennes ne remontent qu'à 1994. À notre connaissance, il n'existe qu'un seul papier économétrique publié sur ce sujet. Il s'agit de l'étude de [Abdullah and Morley \(2014\)](#).

En outre, la majorité des modèles théoriques qui ont étudié l'effet de la fiscalité environnementale sur la croissance économique supposent que le gouvernement finance ses dépenses uniquement par les taxes et que le budget d'Etat est équilibré à chaque période, évitant ainsi tout fardeau associé au remboursement de la dette publique.

Dans cette thèse, nous contribuons à la littérature sur la croissance économique et l'environnement en testant empiriquement les effets de la fiscalité environnementale sur la croissance économique à court et long terme. Notre approche s'appuie sur les intuitions théoriques mises en évidence par la littérature économique et exploite différentes bases de données sur la croissance et la fiscalité environnementales.

### **Questions de recherche :**

L'objet de cette thèse est construit dans le but de répondre empiriquement aux questions suivantes:

1. *Quelle est la nature de la relation entre la fiscalité environnementale et le taux de croissance économique à court et à long terme?*
2. *Est-ce que cette relation diffère entre les pays qui ont implémenté la réforme de la fiscalité environnementale et ceux qui ne l'ont pas implémentée?*
3. *L'effet de la fiscalité environnementale sur le taux de croissance économique est-il sensible au niveau des autres variables dans l'économie ?*
4. *Dans quelles mesures, le capital physique, le capital humain et l'innovation sont-ils les canaux par lesquels les taxes sur l'énergie affectent la croissance économique ?*
5. *Est-ce que l'existence et le niveau de la dette publique modifie l'impact des taxes sur l'énergie sur ces canaux et donc sur la croissance économique?*

### **Contexte et revue de littérature**

Depuis la révolution industrielle, la croissance économique a connu un rythme soutenu, malgré des fluctuations conjoncturelles plus ou moins amples. Elle est ainsi devenue à la fois objectif et moyen des politiques publiques. Elle est ainsi le paramètre clé des budgets publics et souvent assimilé à la réussite de toute politique économique. Néanmoins, la croissance économique a également été accompagnée par grands sacrifices de ressources naturelles et d'un niveau très élevé d'émissions polluantes. Durant la période 1960-2013, les émissions de

CO2 provenant de la consommation de carburant liquide dans le monde ont augmenté de 3 millions (kt) en 1960 à presque 12 millions (kt) en 2013<sup>3</sup>.

Pour corriger ces externalités négatives de développement économique, [Pigou \(1920\)](#) a proposé une taxation sur les activités polluantes. Le but de cette taxe est d'internaliser le coût social des activités économiques. Cette proposition a ensuite été acceptée par les décideurs publics, et plusieurs gouvernements européens comme ceux de la France, le Danemark, la Finlande, et la Suède ont introduit progressivement des taxes liées à l'environnement dans leurs dispositifs fiscaux. Aujourd'hui, la fiscalité environnementale ou 'les taxes liées à l'environnement', comme elles sont appelées selon les termes des Nations Unies et d'autres organisations internationales ([United Nations et al. 2003](#)), ont été introduites dans tous les pays de l'OCDE ([OECD, 2006](#)). Cela a poussé les chercheurs au cours des trois dernières décennies à effectuer un grand nombre d'études théoriques afin d'examiner l'effet de la fiscalité environnementale sur la croissance économique. Or, leurs résultats étaient divergents. Deux études basées sur un modèle à générations imbriquées ([Bovenberg and Heijdra, 1998](#); [Wang et al., 2015](#)) montrent que la fiscalité environnementale entraîne une distorsion du taux de rendement du capital physique à court et long terme. Par conséquent, les générations futures souffriront d'un petit stock de capital physique conduisant à un faible niveau de croissance économique à long terme. [Siriwardana et al. \(2011\)](#) ont utilisé un modèle d'équilibre général calculable pour analyser les effets de la taxe carbone sur l'économie australienne. Ils trouvent que l'introduction d'une taxe sur les émissions de dioxydes de carbone peut diminuer le PIB réel de l'Australie à court terme d'environ 0,68 pour cent.

En revanche, plusieurs articles démontrent que la fiscalité environnementale peut stimuler la croissance économique par deux canaux. Le premier canal est le capital humain. [Gradus and Smulders \(1993\)](#) et [Ewijk and Wijnbergen \(1994\)](#) développent le modèle de croissance endogène de [Lucas \(1988\)](#), en supposant que la pollution réduit la capacité d'apprentissage des individus. Ils trouvent que la réduction des émissions de pollution, grâce à la fiscalité environnementale, peut accélérer la croissance économique en améliorant les capacités d'apprentissage des gens. Dans le même contexte, [Hettich \(1998\)](#) et [Oueslati \(2002\)](#), utilisant un modèle à deux secteurs de croissance endogène, montrent qu'une fiscalité environnementale élevée peut augmenter la croissance à long terme par le mécanisme

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<sup>3</sup> Voir le site: <http://data.worldbank.org/indicator/EN.ATM.CO2E.LF.KT?end=2013&start=1960&view=chart>



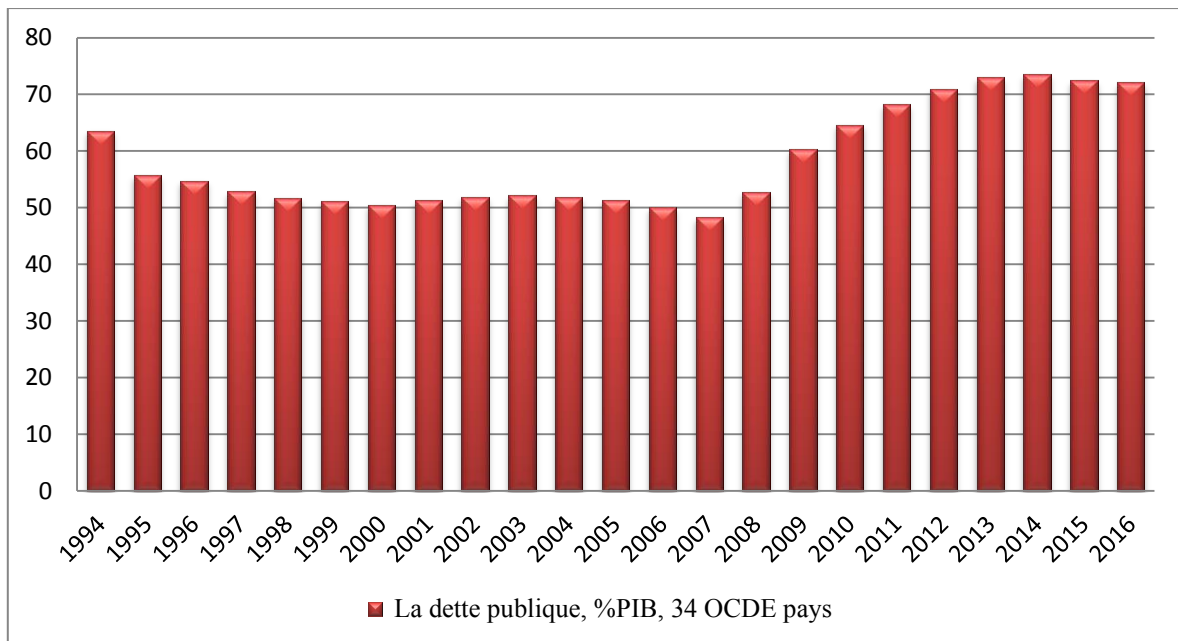
suivant : l'augmentation de la taxe environnementale incite les entreprises à accroître leurs activités privées de réduction de pollution. Cela réduit les ressources allouées à la production et donc réduit la production finale. Une baisse de la production finale mène à réduire la consommation privée des ménages, ce qui pousse les ménages à passer plus de temps à étudier par rapport au temps des loisirs. Cela augmente l'accumulation de capital humain et donc la croissance économique à long terme. Plus récemment, [Pautrel \(2012\)](#) démontre que lorsque la croissance à long terme s'explique par l'accumulation du capital humain, les effets de la pollution sur l'espérance de vie peuvent expliquer par eux-mêmes l'influence de l'environnement sur la croissance. Dans ce cas, une taxe environnementale peut stimuler la croissance économique en diminuant la pollution, ce qui affecte positivement la santé publique et augmente l'espérance de vie. Une augmentation de l'espérance de vie diminuera la fréquence de remplacement des générations et réduira ainsi la perte de connaissances due à ce remplacement. Par conséquent, cela augmente l'accumulation globale de capital humain et le taux de croissance à long terme.

Le deuxième canal par lequel la fiscalité environnementale peut stimuler la croissance économique est l'innovation. Plus précisément, il s'agit de l'innovation environnementale. Selon [Porter \(1991\)](#) et [Porter and van der Linde \(1995\)](#), une réglementation environnementale stricte, mais bien pensée, peut stimuler l'innovation, ce qui augmente la compétitivité des entreprises ainsi que celle des nations. [Nakada \(2004\)](#); [Aloi and Tournemaine \(2011\)](#); et [Ambec et al., \(2013\)](#) montrent que la taxe environnementale peut conduire à une intensité de recherche plus élevée car elle induit une réaffectation de ressources vers des activités de R & D qui sont un input majeur des processus d'innovation. De même, [Hart \(2004, 2008\)](#) confirment que la taxe environnementale encourage les investissements dans la technologie de réduction d'émissions et ainsi améliorer la croissance économique. [Acemoglu et al. \(2012\)](#), en utilisant un modèle de deux secteurs (entrées propres et sales) de changement technique dirigé, montrent l'importance des instruments de la politique environnementale (les taxes sur le carbone et les subventions de recherche) pour orienter l'innovation vers les technologies propres. Récemment, [Hattori \(2017\)](#) emploie un modèle d'innovations environnementales endogènes et monopolistiques pour déterminer les conditions dans lesquelles les taxes sur les émissions peuvent stimuler l'innovation environnementale. Il montre que l'introduction d'une augmentation des taxes sur les émissions encourage l'innovation et la diffusion de technologies respectueuses de l'environnement si l'élasticité-prix de la demande de produits polluants est faible et / ou le fardeau fiscal pour les entreprises polluantes est faible.

Les études empiriques sur la politique environnementale et l'innovation ne présentent pas un consensus sur l'effet positif de la fiscalité environnementale sur l'innovation. D'un part, [Costa-Campi et al. \(2017\)](#) en employant un ensemble de données de panel de 22 secteurs manufacturiers espagnols pour la période 2008-2013, constatent que les taxes sur l'énergie n'ont pas d'effet significatif sur l'investissement dans la R&D environnementale du secteur privé. D'autre part, [Haščič et al. \(2010\)](#) se basant sur un échantillon de 80 pays sur la période 2000-2007, trouvent que la rigueur de la politique environnementale joue un rôle important dans le développement de moyens novateurs de réduction de la pollution de l'air et de l'eau et la gestion des déchets solides. Une analyse microéconomique de [Veugelers \(2012\)](#), utilisant un sondage Flamand sur l'éco-innovation de la CEI, confirme également que l'intervention du gouvernement peut affecter les innovations du secteur privé, où les règlements et les taxes sont les instruments les plus efficaces de la politique environnementale pour inciter à l'adoption de technologies propres dans les entreprises privées.

En ce qui concerne la réforme de la fiscalité environnementale, plusieurs chercheurs supposent que quand le gouvernement utilise les revenus générés de la fiscalité environnementale pour réduire d'autres taxes (tels que les impôts sur le revenu et le travail), la croissance économique bénéficie de ce mécanisme, à travers la diminution des effets négatifs de ces taxes sur l'offre de main-d'œuvre, l'épargne et les décisions d'investissement (voir [Bovenberg and Smulders, 1995](#); [Goulder, 1995](#); [Bovenberg and Mooij, 1997](#); [Fullerton and Metcalf 1997](#); [Markandya, 2005](#); [Oueslati, 2014](#)). Cependant, d'autres études montrent que la taxe environnementale peut affecter négativement la croissance économique, dans certains cas, même avec l'existence de ce mécanisme de redistribution des revenus. Cela peut se produire au sien des entreprises à forte intensité énergétique qui consomment de grandes quantités d'énergie, alors qu'elles possèdent un petit stock de main-d'œuvre. Dans ce cas, la compensation que les entreprises reçoivent grâce à la réduction de la taxe sur le travail ou des cotisations de sécurité sociale peut ne pas correspondre pleinement aux coûts énergétiques supplémentaires générés par l'augmentation des prix de combustible fossile à cause des taxes sur la pollution. Dans cette situation, la taxe environnementale augmentera le coût de production et nuira donc à la croissance économique, même avec l'existence de la redistribution des revenus de la fiscalité environnementale ([Andersen et al, 2007](#)).

Il est à noter que la majorité des travaux sur la fiscalité environnementale et la croissance économique suppose que le budget public est équilibré à chaque période, et ainsi la dette publique est nulle. Or, une des caractéristiques des économies avancées au cours des dernières années est le ratio élevé de la dette publique au produit intérieur brut (PIB) (voir [figure 1](#)).



Source : Les calculs de l’auteur sont basés sur une base de données des perspectives économiques mondiales (Fond Monétaire International).

*Figure 1. La dette brute des administrations publiques en % du PIB, une moyenne pour les 34 pays de l'OCDE (1994-2016).*

Avec des niveaux élevés de la dette publique, la politique budgétaire peut nuire à la croissance économique, alors que les faibles niveaux de la dette publique permettent à la politique budgétaire de promouvoir le progrès économique ([Baharumshah et al, 2017](#); [Bhattarai et al., 2014](#); [Chen et al. 2016](#); [Gogas et al., 2014](#); [Galstyan and Velic, 2017](#); [Gwartney et al., 1998](#); [Teles and Cesar Mussolini, 2014a](#)). Comme la taxe est l'un des outils de la politique budgétaire, l'effet de la fiscalité environnementale sur la croissance économique pourrait être affecté par l'existence et le niveau de la dette publique. Le canal par lequel la dette publique peut affecter la croissance économique est l'investissement. Un niveau élevé de la dette publique peut avoir une influence négative sur l'investissement par l'absorption d'une partie de l'épargne des gens ([Teles and Cesar Mussolini, 2014a](#)), l'augmentation des taux d'intérêt ([Gogas et al., 2014](#); [Gwartney et al. 1998](#); [Mueller, 2004](#)), la

dépréciation des taux de change (Galstyan and Velic, 2017), et l'augmentation du taux d'inflation (Bhattarai, Lee, and Park, 2014).

Après avoir présenté la littérature sur le sujet, nous allons maintenant présenter le plan de la thèse et les méthodes que nous avons utilisées afin de répondre aux questions posées.

## **Plan et stratégie de réponse**

Cette thèse est une contribution empirique au débat sur la relation entre la fiscalité environnementale et la croissance économique. Elle est constituée de trois chapitres. Dans le premier chapitre, notre analyse se focalise sur les revenus totaux générés par les taxes liées à l'environnement, mesurés en pourcentage de Produit Intérieur Brut (PIB). Nous utilisons ces revenus comme un proxy des taxes liées à l'environnement. Dans ce chapitre, nous cherchons à répondre empiriquement aux trois questions suivantes :

1. *Les revenus totaux des taxes liées à l'environnement sont-ils associés au taux de croissance économique à court et à long terme?*
2. *Cette relation est-elle sensible au niveau des revenus générés par les taxes liées à l'environnement ou au niveau des autres variables dans l'économie?*
3. *La relation entre les revenus totaux des taxes liées à l'environnement et le taux de croissance économique diffère-t-elle entre les pays qui ont mis en œuvre des réformes de la fiscalité environnementale et ceux qui ne l'ont pas fait?*

En ce qui concerne la deuxième question, nous supposons que la relation entre les revenus totaux des taxes liées à l'environnement et le taux de croissance économique pourrait être sensible au niveau initial de richesse du pays, mesuré par le niveau initial du PIB par habitant.

Afin de répondre à la première question à court terme, nous construisons un modèle empirique de la croissance qui contrôle les principales variables explicatives de la croissance économique selon la littérature empirique et théorique. Ces variables comprennent quatre groupes qui s'ajoutent aux revenus totaux des taxes liées à l'environnement. Le premier groupe se compose des variables conditionnelles de la croissance qui sont le niveau initial du PIB réel par habitant, le taux de croissance de la population active totale, et l'accumulation de

capital physique mesurée par la variation annuelle de la formation brute de capital fixe en pourcentage du PIB. Le deuxième groupe inclut les variables du capital humain qui est mesuré par l'indice de compétences humaines réalisé par le laboratoire d'économie appliquée au développement à l'université de Toulon en France<sup>4</sup>. Suite à [Baldacci et al. \(2008\)](#) et [Chi \(2008\)](#), nous utilisons deux variables pour mesurer l'effet du capital humain. Il s'agit du niveau initial du capital humain, et de la variation annuelle du capital humain. Le troisième groupe comprend les variables de la politique budgétaire qui sont la dépense productive, les taxes distordantes, et l'équilibre budgétaire. Les trois variables sont mesurées en pourcentage du PIB. Le dernier groupe inclut deux variables macroéconomiques : le taux d'inflation et l'ouverture au commerce international des biens.

Afin de répondre à la première question dans une perspective de long terme, nous utilisons des valeurs retardées de toutes les variables explicatives pour cinq périodes, chaque période étant d'un an. Cette méthode nous permet d'examiner si les revenus générés des taxes liées à l'environnement durant les années précédentes sont associés au taux de la croissance économique dans l'année courante.

Pour explorer si l'effet de la fiscalité environnementale sur le taux de la croissance économique est sensible au niveau des revenus réalisés ou au niveau initial de la richesse, nous permettons au « proxy » des taxes liées à l'environnement d'interagir entre-elles, et avec le niveau initial du PIB par habitant.

Nous répondons à la dernière question dans ce chapitre de la manière suivante. D'abord, nous collectons des informations sur la mise en œuvre des réformes fiscales liées à l'environnement (RFE) dans les pays de l'OCDE en utilisant des revues de littérature et des rapports politiques sur (RFE). Ensuite, nous utilisons ces informations pour diviser les pays de l'OCDE en deux groupes : les pays qui ont mis en œuvre les réformes et les pays qui ne les ont pas instaurées. Enfin, nous effectuons la même analyse empirique utilisée dans la première question sur ces deux échantillons.

Les données utilisées pour estimer les paramètres des modèles employés dans ce chapitre sont des données de panel de 31 pays de l'OCDE durant la période 1994-2013. Le Chili, le

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<sup>4</sup> Voir le site: <http://lead.univ-tln.fr/>

Mexique et les États-Unis ont été exclu d'échantillon, en raison des données manquantes sur la variable de la « dépenses productives ». Les autres données manquantes ont été traitées par la méthode de l'imputation multiple qui a amélioré la qualité des données et contribué à l'obtention d'estimations fiables. L'approche des effets aléatoires corrélés (EAC) développée par [Wooldridge \(2010\)](#) a été utilisé pour estimer les coefficients des modèles dans ce chapitre. Ensuite, nous avons vérifié la robustesse des modèles en utilisant trois tests. Le premier est le test de 'QIC' développé par [Cui and others \(2007\)](#). Ce test vérifie si certaines ou l'ensemble des quatre catégories de variables explicatives que nous avons collectées devraient être incluses dans la régression. Le deuxième test est la 'variance facteur d'inflation'. Nous utilisons ce test pour voir s'il y a une multi-colinéarité entre les variables explicatives. Le dernier test est le test de racine unitaire en panel. Ce test a été utilisé pour vérifier si les séries chronologiques du taux de croissance économique (gr) et des revenus des taxes liées à l'environnement (ETRT) sont stationnaires. Les résultats de ces trois tests montrent que les quatre groupes de variables explicatives devraient être inclus dans la régression, qu'il n'y a pas de problème de la multi-colinéarité, et que les séries chronologiques du (gr) et (ETRT) sont stationnaires.

Dans le premier et le deuxième chapitre de cette thèse nous nous intéressons à étudier la nature de relation, davantage que l'effet causal des taxes environnementales sur le taux de croissance économique. C'est la raison pour laquelle nous utilisons le modèle d'EAC qui permet de traiter le problème d'endogénéité causé par la corrélation entre les variables du modèle et les effets non observés des facteurs invariants dans le temps ([Bache et al., 2013](#)). Toutefois, l'endogénéité peut également survenir en raison d'une causalité simultanée. Ce type d'endogénéité va être traité au troisième chapitre en utilisant des variables instrumentales.

Les résultats d'estimation sur la première question montrent qu'il n'y a pas de relation statistiquement significative entre les revenus totaux des taxes liées à l'environnement et le taux de la croissance économique à court et à long terme. Mais, quand nous permettons aux taxes liées à l'environnement d'interagir avec eux-mêmes et avec le niveau initial du PIB par habitant, cette relation devient significative et négative à court et à long terme. Cependant, les résultats montrent que le premier terme d'interaction est statistiquement insignifiant, tandis que le second est significatif. Nous concluons que l'effet des taxes liées à l'environnement sur le taux de croissance économique n'est pas sensible au niveau des revenus réalisés, mais il est

sensible au niveau initial de la richesse du pays. Les résultats montrent également que le terme d'interaction entre (ETRT) et le niveau initial du PIB a un signe positif, ce qui indique que plus le niveau initial de richesse d'un pays croît, plus l'augmentation des revenus des taxes liées à l'environnement entraîne une augmentation du taux de croissance économique. Les estimations sur la dernière question dans ce chapitre révèlent des différences notables entre les deux groupes de pays. L'association entre les revenus des taxes liées à l'environnement et le taux de croissance économique, à court et à long terme, est statistiquement non-significative dans les pays qui n'ont pas mis en œuvre des réformes, alors que cette association est statistiquement significative et négative dans les pays qui ont mis en œuvre des réformes.

Dans le deuxième chapitre, notre analyse se concentre sur les taxes sur l'énergie, qui est la catégorie la plus importante parmi les taxes liées à l'environnement au niveau des revenus réalisés. Le proxy de la fiscalité environnementale que nous avons utilisé au premier chapitre mesure les revenus générés des taxes liées à l'environnement en pourcentage de PIB. Or, cette mesure ne tient pas compte de la variation de l'assiette fiscale, affaiblissant ainsi le rôle qui pourrait être joué par la fiscalité environnementale dans l'économie. Cela peut justifier la relation non-significative à court et long terme entre les revenus totaux des taxes liées à l'environnement et le taux de la croissance économique, lorsque nous ne prenons pas en compte leurs interactions avec d'autres variables dans l'économie. Par conséquent, dans le deuxième chapitre, nous proposons une nouvelle mesure de la fiscalité environnementale qui tient compte de la variation de l'assiette fiscale. Toutefois, étant donné que la fiscalité environnementale est imposée sur différentes bases (l'énergie, des véhicules à moteur, des substances appauvrissant l'ozone, l'eau et eaux usées, la gestion des déchets, l'exploitation minière et extractive, et d'autres taxes liées à l'environnement), il est difficile de construire une base d'imposition commune pour ces facteurs. C'est la raison pour laquelle, nous décidons de concentrer notre analyse sur une seule catégorie de taxes liées à l'environnement : les taxes sur l'énergie.

Comme les taxes sur l'énergie portent essentiellement sur la consommation de combustibles fossiles, nous considérons la consommation finale totale des produits du charbon, des produits pétroliers, du gaz naturel et de l'électricité produite à partir du combustible fossile comme une base d'imposition des taxes sur l'énergie. Par conséquent, le proxy des taxes sur l'énergie est calculé comme suit : les revenus générés des taxes sur l'énergie mesurés en millions de dollars

américains divisé par la consommation finale totale de produits énergétiques polluants mesurés en tonnes d'équivalent pétrole.

Ensuite, nous avons utilisé ce proxy pour atteindre deux objectifs. Premièrement, explorer la nature des relations entre les taxes sur l'énergie et le taux de croissance économique à court et long terme. Deuxièmement, étudier si l'effet de ces taxes sur le taux de croissance économique est sensible au niveau de trois variables dans l'économie. Ces variables sont les suivantes:

- La consommation de produits énergétiques polluants par rapport à la consommation d'énergie propre
- Le niveau initial de la richesse d'un pays
- Le degré d'ouverture commerciale des biens d'un pays

Pour atteindre nos objectifs, nous utilisons la même méthodologie économétrique que celle employée au premier chapitre. Les résultats montrent que les taxes sur l'énergie sont négativement associées au taux de croissance économique à court terme, mais cette relation n'est pas significative à long terme. Cependant, lorsque nous permettons à ces taxes d'interagir avec d'autres variables, cette relation devient significative et négative à court et long terme. En outre, les résultats révèlent que le terme d'interaction entre les taxes sur l'énergie et le proxy de la consommation de produits énergétiques polluants a un signe significatif et négatif à court terme et pour certaines périodes à long terme. Cela signifie que l'effet des taxes énergétiques sur le taux de croissance économique est négativement sensible au niveau du combustible fossile utilisé dans l'économie, et plus ce niveau augmente, plus les taxes sur l'énergie nuisent au taux de croissance économique. D'autre part, nous constatons que le terme d'interaction entre les taxes sur l'énergie et le niveau initial de PIB par habitant a un signe positif à court et à long terme. Cela indique que l'effet des taxes énergétiques sur le taux de croissance économique est positivement sensible au niveau initial de la richesse du pays. En d'autres termes, on peut dire que l'expansion des taxes sur l'énergie dans les pays qui ont un haut niveau de richesses favorisera le taux de croissance économique, alors que ces taxes nuiraient à la croissance économique dans les pays à faible richesse. Enfin, nous constatons que l'interaction entre les taxes sur l'énergie et le degré d'ouverture commerciale des biens est négative et significative quand le nombre des années tardés est égal à cinq. Cela montre que plus le niveau d'ouverture commerciale des biens est élevé, plus l'augmentation des taxes énergétiques nuit au taux de croissance économique à long terme. Pour connaître l'effet net de



ces taxes sur le taux de croissance économique, l'effet marginal des taxes énergétiques a été calculé. Les résultats montrent que l'effet marginal est négatif à court terme, toutefois cet effet négatif diminue à long terme et il devient positif quand les variables explicatives sont tardées pour trois et cinq ans.

Dans le troisième chapitre, nous vérifions empiriquement les canaux par lesquelles les taxes sur l'énergie peuvent affecter le taux de croissance économique. Ce chapitre a deux objectifs : premièrement, étudier l'impact potentiel des taxes énergétiques sur le capital physique (l'investissement physique), le capital humain et l'innovation environnementale dans le contexte d'un modèle de croissance endogène, où le capital physique, le capital humain et l'innovation environnementale sont les trois canaux principaux par lesquelles les taxes sur l'énergie peuvent affecter la croissance économique. Deuxièmement, explorer si l'impact des taxes énergétiques sur le capital physique et ensuite sur le taux de croissance économique est sensible à l'existence et au niveau de la dette publique. Autrement dit, est-ce que la présence et le niveau de la dette publique modifiera l'effet des taxes énergétiques sur le capital physique et ensuite sur le taux de croissance économique ?

Pour atteindre le premier objectif, nous utilisons des spécifications générales pour le taux de croissance économique, l'investissement physique total, le capital humain, les émissions de CO<sub>2</sub> et les innovations environnementales en nous appuyant sur un ensemble de variables explicatives utilisées dans la littérature existante. L'investissement physique, le capital humain et l'innovation environnementale sont considérés comme des variables endogènes dans l'équation du taux de croissance économique, et les autres variables explicatives de la croissance sont considérées comme des variables exogènes. La littérature théorique suppose qu'il y a un impact direct et négatif des taxes sur l'énergie sur l'investissement physique. Pour tester cette hypothèse, le proxy des taxes sur l'énergie est introduit en tant que variable exogène dans l'équation d'investissement physique. Les modèles théoriques ([Gradus and Smulders, 1993](#); [Ewijk and Wijnbergen, 1994](#); [Vellinga, 1999b](#) ; [Pautrel, 2012](#)) supposent également qu'il existe un effet indirect de ces taxes sur le capital humain, à travers leurs impacts sur les émissions polluantes. Cette hypothèse est testée en deux étapes : premièrement, nous examinons l'effet des émissions polluantes sur le capital humain. Deuxièmement, nous explorons l'impact des taxes sur l'énergie sur les émissions polluantes. À cette fin, les émissions de CO<sub>2</sub> ont été choisies comme un proxy des émissions polluantes. Ce choix est basé sur les résultats de [Raymond \(2009\)](#). Il a trouvé qu'il y a une très forte corrélation entre

les paires CO<sub>2</sub> & NO<sub>x</sub>, CO<sub>2</sub> & SO<sub>x</sub>, NO<sub>x</sub> & SO<sub>x</sub>, et que prenant l'un ou l'autre donne les mêmes résultats. Nous considérons ce proxy comme une variable endogène dans l'équation du capital humain, et le proxy des taxes sur l'énergie en tant que variable exogène dans l'équation du CO<sub>2</sub>. Pour tester l'effet direct des taxes énergétiques sur l'innovation environnementale, le proxy des taxes sur l'énergie est inclus en tant que variable exogène dans l'équation de l'innovation environnementale.

Afin de savoir si la *présence* de la dette publique modifiera l'effet des taxes énergétiques sur l'investissement physique et ensuite sur le taux de croissance économique, la dette publique est introduite comme une variable exogène dans l'équation d'investissement physique, et nous ré-estimons notre modèle. Enfin, pour examiner si l'effet des taxes énergétiques sur l'investissement physique est sensible au *niveau* de la dette publique, nous permettons au proxy des taxes sur l'énergie d'interagir avec la dette publique dans l'équation d'investissement physique, puis nous ré-estimons le modèle.

L'analyse a été réalisée à court et à long terme en utilisant le modèle des équations simultanées pour 31 pays de l'OCDE sur la période 1994-2013. La méthode d'imputation multiple a été implémentée afin de compléter les données manquantes. Ensuite, nous avons utilisé l'estimateur du processus mixte conditionnel développé par [Roodman \(2011\)](#) pour estimer les coefficients du modèle. Les variables instrumentales ont été utilisées pour traiter le problème d'endogénéité.

Les résultats montrent un impact négatif des taxes sur l'énergie sur l'investissement physique à court et à long terme. Cet impact est négativement sensible à la présence et au niveau de la dette publique. De plus, nous avons constaté qu'il y a un effet indirect des taxes énergétiques sur le capital humain par son impact sur les émissions de CO<sub>2</sub>. En effet, les taxes sur les produits énergétiques sont capables de réduire l'augmentation et l'accumulation des émissions de CO<sub>2</sub> qui ont un impact négatif sur le capital humain à court et à long terme. De plus, les résultats empiriques montrent que les taxes sur l'énergie peuvent encourager l'innovation environnementale à court et à long terme. Cependant, l'innovation environnementale ne favorise le taux de croissance économique qu'après deux ou trois ans.

# 1. Chapter 1: Environmentally related taxes, reforms and economic growth: An empirical analysis of panel data

## Abstract

This chapter explores the relationship between environmentally related taxes and economic growth rate. The analysis also investigates whether this relationship differs between countries which have implemented environmental tax reforms (ETRs) and ones which have not. In order to complete unbalanced data set of (31) OECD countries over the 1994 - 2013 period, we implemented a multiple imputation method using an Expectation Maximization Bootstrapped algorithm. Multiple imputation has been successfully done, resulting in improved data and inferences validity. Estimation results showed that when we allowed environmentally related tax revenues to interact with an initial level of real GDP per capita, the overall revenues of these taxes were negatively associated with economic growth rate, in the short- and long- term. Furthermore, we showed that the higher the initial level of GDP per capita, the more environmentally related tax revenues can promote economic growth rate. The analysis also revealed that the relationship between environmentally related tax revenues and economic growth varies between countries that have a mechanism to redistribute environmentally related tax revenues and those that do not.

## 1.1. Introduction

Over the past three decades, all OECD countries have introduced environmentally related taxes to a varying extent in order to reduce pollution and greenhouse gas emissions. Also, in the early 1990s, some of them started implementing environmental tax reforms (ETRs) which are based on a “revenue recycling system” that shifts the tax burden from labor, personal and corporate income to environmentally harmful activities ([European Environment Agency 2005, 2011](#)). The revenues from environmentally-related taxes are used, for example, to decrease labor taxes or social security contributions, with a view to stimulating employment and promoting economic growth.

In recent literature, the impact of environmental taxes on economic growth has been widely debated on a theoretical level. However, there is a disagreement on the short- and long-term effects of environmental taxes on economic growth and little empirical evidence on this topic have been examined to date. In this chapter we make an econometrical contribution to the debate about the growth – environmental tax relationship. We believe that exploring the nature of the relationship between environmentally related taxes and economic growth is an important issue, as it shows whether the use of tax as an instrument for environmental policy has any correlation and whether it will have a positive or negative correlation with economic growth. The available data on this topic is not abundant as the OECD statistics only provide data about the revenue generated from environmentally related taxes but not about their rates. Therefore, we used this revenue as a proxy of environmentally related taxes, and our analysis focused on the total revenue of these taxes. According to the data provided by the OECD, the overall revenue of environmentally related taxes, in the OECD zone, has increased from 420.754 billions US\$ in 1994 to 786.134 billion US\$ in 2013. This significant rise in the revenues made us wonder whether the nature of the relationship between environmentally related taxes and economic growth is sensitive to the level of revenue generated from these taxes. In other word, we want to explore whether there is a non-linear relationship between these revenues and economic growth rate. On the other hand, and during the negotiations of the Paris Agreement (2015), a dispute between developing and developed countries has emerged on the responsibility for the accumulation of carbon dioxide in the atmosphere during the nineteenth and twentieth centuries. The developing countries consider that they are not responsible for these emissions and that the measures envisaged today should not be barriers to economic growth which they are just beginning to reap its benefits. This motivated us to suppose that the nature of the relationship between environmentally related taxes revenue and economic growth rate may depend on the country's initial level of GDP per capita, justifying that as follows: according to the three-sector theory, when the level of GDP per capita increases, agriculture and industry's share in GDP declines in favor of an increase in service's share in GDP. This means, when the initial level of GDP per capita is low, the contribution of agriculture and industry in GDP will be high. As the inputs of the production process in these two sectors heavily rely on physical capital and raw materials, like machinery, equipment, fossil fuels and electricity, the production will lead to a high level of pollutant emissions and pollution, forming a broad tax base of environmental tax. Thus, the introduction of the environment tax in countries with a low level of GDP per capita will harm economic growth through increasing the cost of production inputs in these two sectors. This

situation may be reversed in countries that have a high level of initial GDP per capita, where the contribution of agriculture and industry in GDP declines compared to the service sector. In this case, the production process depends on human capital more than physical capital and raw materials, leading to a decrease in pollutant emissions. In addition, rich countries have high capacity for improving energy use efficiency and productivity of physical capital in agriculture and industry sectors, and thus reduce the pollutant emissions which are the tax base of environmentally related taxes. For these reasons, the initial level of a country's richness measured by the initial level of GDP per capita can affect the nature of the relationship between environmentally related taxes and economic growth.

On the other hand, and in the light of the wave of environmental tax reforms that started in the early 1990s in a number of OECD countries, the majority of theoretical studies suppose that these reforms will generate a positive impact of environmental tax on economic growth (See [Bovenberg and Smulders, 1995](#); [Goulder, 1995](#); [Lans Bovenberg and de Mooij, 1997](#); [Fullerton and Metcalf, 1997](#); [Markandya, 2005](#)). However, there is no empirical study to date that shows whether the nature of the relationship between environmentally related taxes and economic growth differs between the countries which made these reforms and those which did not.

Consequently, the main contributions of this chapter to literature are by answering empirically the following three questions: Are the overall environmentally related tax revenues associated with the economic growth rate in the short and long term? Is this relationship sensitive to the level of revenue generated from environmentally related taxes or to the level of other variables in the economy? Does the relationship between overall environmentally related tax revenues and the economic growth rate differ between the countries which have implemented ETRs and those which have not?

To achieve our goal, the analysis was divided into two stages. The first stage was based on a sample of 31 OECD countries from 1994 to 2013. Then, using information collected from academic literature, in particular [Oueslati et al. \(2017\)](#), and policy reports about ETRs, we divided the sample into two groups: the countries which have established ETRs, over these years, and the countries which have not. After that, we performed the same empirical analysis used in the first stage on these two samples. We found that the relationship between environmentally related tax revenue and economic growth rate is statically insignificant in the

short and long term. However, when we allowed overall environmentally-related tax revenues to interact with the initial level of real GDP per capita, this relationship became significant and negative. This reflects the importance of a country's richness level in determining the nature of the relationship between environmental taxation and economic growth. Moreover, this shows that the negative effect of environmentally-related taxes on economic growth rate occurs through the interaction of these taxes with other variables in the economy. The results also revealed that this association is not sensitive to the level of revenue generated from these taxes, but it is positively sensitive to the country's initial level of GDP per capita. The positive sign of the interaction term between environmentally related taxes and the initial level of GDP per capita means that, the higher the initial level of GDP per capita, the more environmentally related tax revenues can promote economic growth rate. Our findings revealed also that the relationship between environmentally related tax revenues and economic growth rate varies between the countries that implemented ETRs and those that did not. More precisely, this association is statistically insignificant in the countries which have not established ETRs, whereas it is statistically significant and negative in the countries which have established such reforms.

The rest of this chapter was organized as follows. Section (1.2) presents the literature review of environmental taxation and economic growth. Section (1.3) provides an overview of the development in GDP per capita growth rate and different environmentally related tax revenues in OECD countries over the last two decades. Section (1.4) describes empirical strategy including the model and data used. In section (1.5), we discuss the empirical results on a short and long term basis. The last section concludes the chapter by summarizing the main findings.

## **1.2. Literature Review**

Environmental taxation could achieve the desired environmental improvement at minimum cost to society at large (Baumol and Oates, 1971). This approach has now become a principal approach to justify environmental taxes (Ekins and Speck, 2011). However, the debate about the effect of these taxes on economic growth is still a contentious issue among researchers to date. Existing research has used a number of different models to address this question. Bovenberg and Heijdra (1998) using an overlapping generations model and modeling the quality of the environment as a durable consumption good, found that the environmental tax increase, makes the future generations suffer from a smaller physical capital stock, but benefit

from a larger stock of natural capita. This result is reversed with the older generations. Thereby, at the long term, the economic growth decreases due to the low physical capital that the younger generation will have to work with. Similarly, [Wang et al. \(2015\)](#), based on an overlapping generation model, showed that pollution tax can reduce pollution but it causes a distortion in the rate of return to capital and thus damage growth. In the same context, [Siriwardana et al. \(2011\)](#) built a computable general equilibrium (CGE) model to analyze the effects of carbon tax on the Australian economy. They found that Australia's real GDP may decline, in the short term, by about 0.68 per cent after the introduction of a \$23 tax on carbon dioxide emissions.

In contrast, several papers demonstrated that environmental taxation policy may boost economic growth via a variety of channels. [Lans Bovenberg and Smulders \(1995\)](#), [Ewijk and Wijnbergen \(1995\)](#) and [Lans Bovenberg and de Mooij \(1997\)](#) propose that environmental tax improves the quality of the environment, which increases the productivity of other productive inputs, and thus the total factor productivity of the economy, thereby stimulating economic growth. Based on the Uzawa–Lucas endogenous growth model extended by elastic labor supply, [Hettich \(1998\)](#) and [Oueslati \(2002\)](#) showed that, a higher environmental tax enhances long-term growth as follows: The increased environmental tax induces firms to raise their private abatement activities, which reduces final output net of abatement at the expense of households' consumption. The reduction in private consumption in turn causes a substitution away from leisure towards time spent studying, which boosts human capital accumulation and thus growth. In addition, environmental tax can lead to higher research intensity as it induces a reallocation of resources towards R&D activities, which are the engine of growth ([Nakada 2004](#); [Aloi and Tournemaine, 2011](#); [Ambec et al., 2013](#)). Similarly, [Hart \(2004, 2008\)](#) argued that environmental tax encourages investment in emissions-saving technology and thus enhances growth. The relationship between environmental taxation and innovation have also examined by [OECD \(2010\)](#). The study confirmed that environmental taxation can and does increase innovation and diffusion of environmental technologies. Some researchers have demonstrated that pollution has a direct impact on long-term growth because it reduces the ability to learn ([Gradus and Smulders, 1993](#); [Ewijk and Wijnbergen 1995](#); [Vellinga, 1999](#); [Withagen and Vellinga, 2001](#)). They also argued that environment does not influence long-term accumulation of human capital if this direct impact of pollution on education is not taken into account. In contrary to this condition, [Pautrel \(2012\)](#) demonstrated that, when the long-run growth is driven by human capital accumulation, the effects of pollution on life expectancy may explain by themselves the influence of environment on growth. In this case,

environmental tax can stimulate economic growth through decreasing pollution which positively affects public health and increases life expectancy. The former decreases the frequency of generations' replacement and thus reduces the loss of knowledge due to this replacement. Therefore, this increases the aggregate human capital accumulation and the growth rate in the long term.

On the other hand, some theoretical research in this area showed contradictory effects of environmental tax levels on economic growth. For instance, [Ono \(2003\)](#) with an overlapping generations model of growth and the environment, demonstrated that, in the long-run, environmental taxation has two opposing effects on economic growth. When the tax rate is high, the firms emit a lower flow of pollution which leads to a higher quality of the environment bequeathed to future generations, which implies a positive income effect. Thereby, the new generation can allocate a larger part of its resources toward savings (and investment) instead of pollution abatement activities, which increases the accumulation of productive capital and then economic growth. On the other side, a higher tax imposes a heavier burden on the firms. Therefore, the wages that they pay to workers and the taxes paid to the government decrease. This negative income effect causes a decline in savings and investment, thereby lowering economic growth rate. In contrast, these effects are reversed with a low level of environmental tax rate. In a similar context, but by using an overlapping generations model where long-run growth is driven by accumulation of physical capital stock (AK model à la [Romer \(1986\)](#)), [Pautrel \(2009\)](#) showed that, when pollution does not affect life expectancy, the negative impact of the environmental policy on growth is limited if agents smooth their consumption over time; whereas when pollution affects life expectancy, economic growth rate and the environmental taxation describe an inverted U-shaped relationship.

Other theoretical studies supposed that the positive impact of environmental tax on economic growth can be generated not only via improving the quality of the environment but also through recycling environment tax revenues. When the government uses these revenues to reduce the rates of distortionary taxes in the economy (such as income and labor taxes), economic growth is expected to have a positive effect from such a mechanism, through decreasing the negative effects of these taxes on labor supply, saving, and investment decisions (See [Bovenberg and Smulders, 1995](#); [Goulder, 1995](#); [Bovenberg and Mooij, 1997](#); [Fullerton and Metcalf, 1997](#); [Markandya, 2005](#); [Oueslati, 2014](#)). Another scenario of environmental tax reforms associated with a change in the structure of public spending has



been proposed by [Oueslati \(2015\)](#). He finds that the use of environmental tax revenue to increase education spending has a greater positive impact on stimulating growth.

However, environmental tax can negatively affect economic growth in some cases, even with the existence of ETRs, through the following mechanism: The reform based on using energy taxes revenue to reduce distortionary tax rates changes the relative costs of the products produced by all companies and in particular by energy-intensive companies. This change comes from increasing the costs of fossil fuels, and decreasing the costs of labor and/or capital. Therefore, the net effect of these changes may be positive or negative according to the structure of labor, capital and fossil fuel consumption in the company. For instance, in energy-intensive companies which consume large amounts of energy, while they have a small labor stock, the compensation that they receive via the reduction in labor tax or social security contributions may not fully match the additional energy costs. In this case, environmental tax increases the cost of production and thus harms economic growth, even with the presence of ETRs ([Andersen et al, 2007](#)). [Goulder \(1995\)](#) suggests also that the positive effect on GDP costs of using energy taxes revenue to finance cuts in income taxes cannot be taken for granted but depends on the level of pre-existing tax rates that is replaced by energy taxation. In the same context, [Ekins et al. \(2012\)](#) explore the implications - for Europe and the rest of the world -of a large-scale ETR in Europe designed to achieve the EU's 2020 greenhouse gas reduction targets, i.e. cutting GHG emissions by 20 % in the period 1990–2020 (or 30 % in a context of global cooperation). In order to investigate whether ETR could deliver these targets, they used two well-known macro-econometric models: E3ME and GINFORS. The results showed that an ETR that meets the emissions' target by imposing a tax on material inputs and recycling all the revenues through a reduction in employers' social security contributions and income taxes would raise employment, lower resource consumption and have a small negative impact on GDP. This is driven by reduction in labor costs, higher household incomes resulting from lower income taxes and higher employment rates, increasing the price of various products according to their direct and indirect carbon content and thus reducing price competitiveness on export markets. However, in other scenarios for the same model, when 10 % of environmental tax revenues are spent on eco-innovation measures and the remaining 90 % recycling through a reduction in employers' social security contributions and income taxes, the loss of international competitiveness is expected to be offset by gains in international trade sector through increasing the exports of renewable technologies ([EEA, 2011](#)). Consequently, the existence of ETRs mechanism can affect the

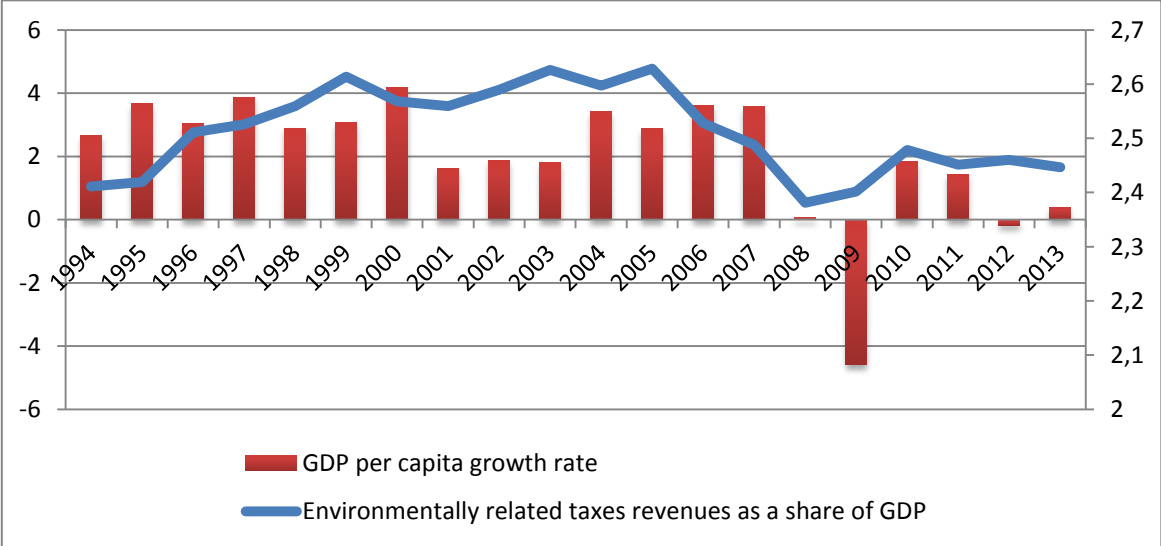
economy through five channels: international trade, employment, human capital, investment and innovation.

Although numerous arguments have been provided regarding the effects of environmental tax on economic growth, the suggested results are often contradictory, and empirical evidence to support these arguments is scarce. To the best of our knowledge, there is only one published econometric study about this topic, which is [Abdullah and Morley \(2014\)](#). This paper evaluated the causal relationship between environmental taxes and economic growth, using the standard Granger non-causality approach. They found some evidence of a short and long-run causal effect from economic growth to environmental taxes; nevertheless there is little evidence of long-run causality in the other direction. These results show an ambiguous relationship between environmental tax and economic growth. It should be also noted that [Abdullah and Morley \(2014\)](#) do not distinguish between the countries that have implemented environmental tax reforms and those that have not. Consequently, rather than studying the causal relationship, we investigated the nature of the relationship between environmentally related taxes and economic growth in the short and long term, including a large set of explicative variables of economic growth. In addition, part of our analysis will be concentrated on investigating whether the nature of this relationship differs between the countries that have implemented ETRs and those that have not. Furthermore, in order to complete our unbalanced data set, we implemented a multiple imputation method using an Expectation Maximization Bootstrapped algorithm.

### **1.3. Development of GDP per capita growth rate and different environmentally related taxes in OECD countries**

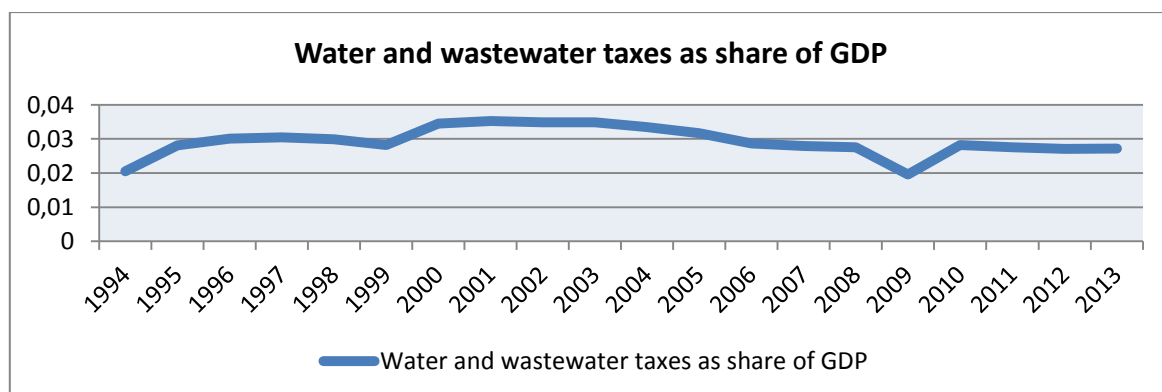
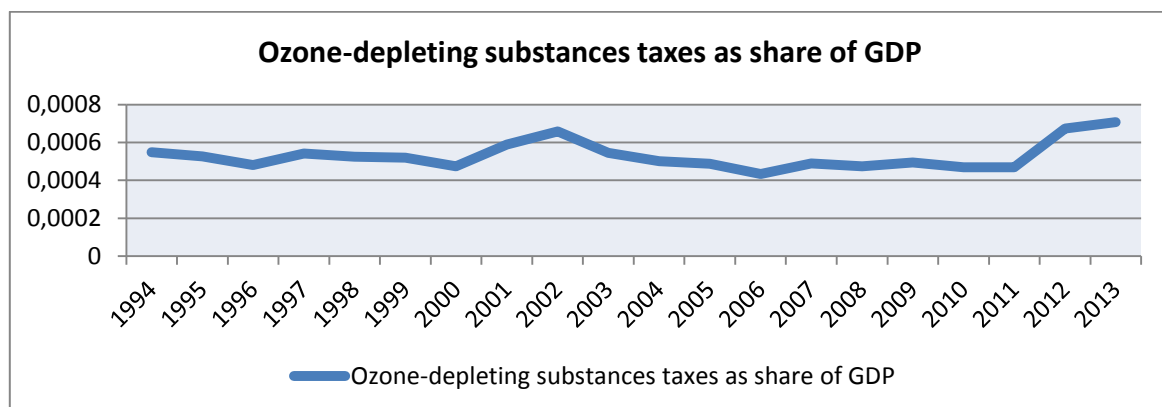
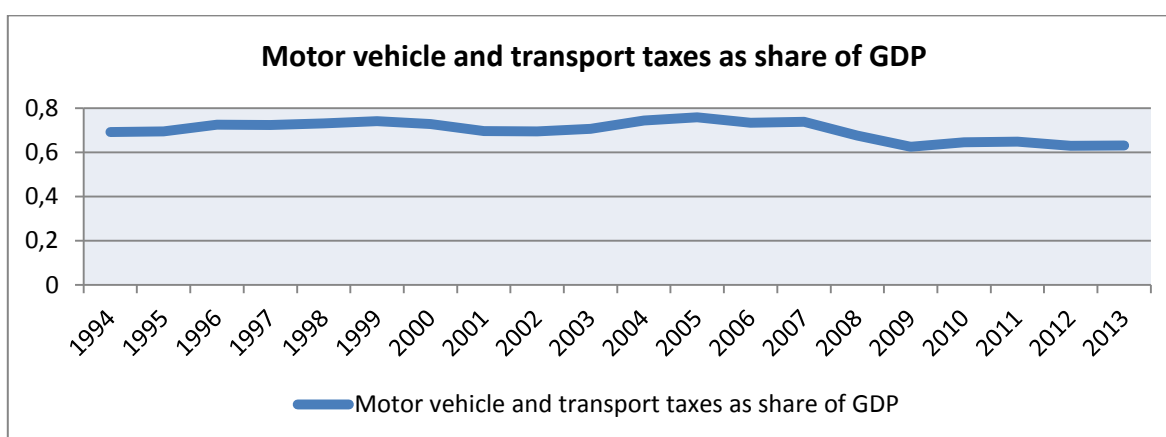
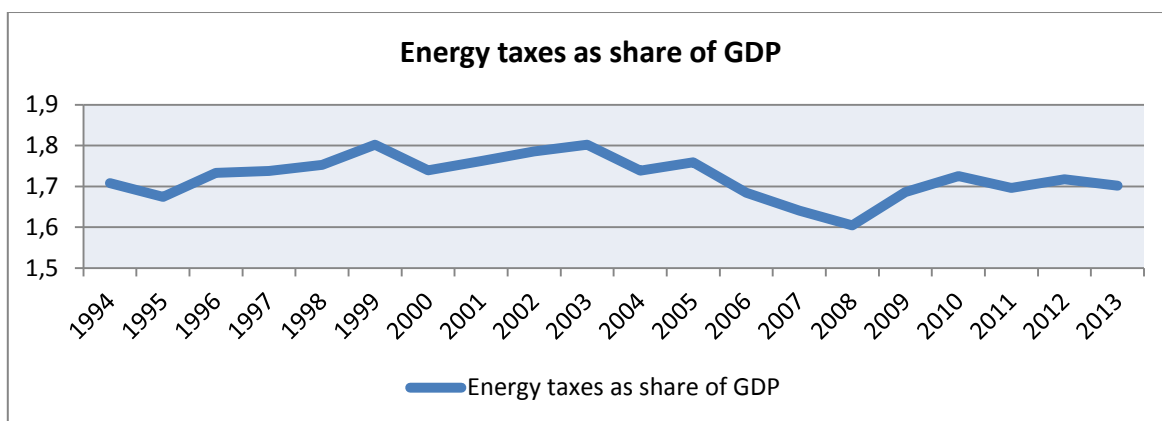
[Figure \(1.1\)](#) demonstrates how the average GDP per capita growth rate and the average share of overall environmentally related tax revenues in GDP of 31 OECD countries have evolved since 1994. [Figure \(1.2\)](#) shows the evolution of the seven categories of environmentally related taxes: *Energy; motor vehicles and transport; ozone-depleting substances; water and wastewater; waste management; mining and quarrying, and other environmentally related taxes*. The mean GDP per capita growth rate shows a rising trend from 1994 to 2000 and reaching 4.18 % in 2000, from which it declined from 2001 to 2003 and stabilized at 1.8% in 2003. After that we can see an increase to 3.57% in 2007, falling sharply in 2008 to stabilize at - 4.57% in 2009, due to the latest world financial crisis in the U.S.A. After its recovery in

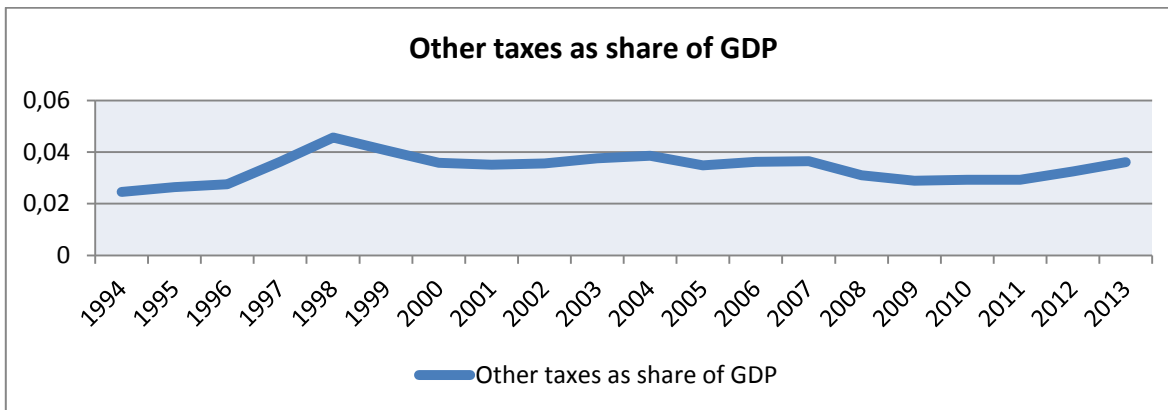
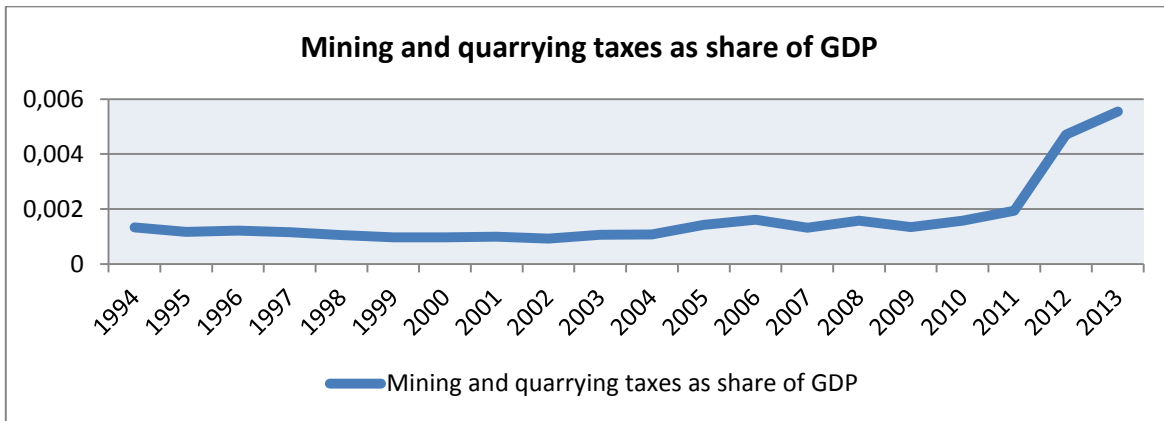
2010, it re-decreased to - 0.17% in 2012. In 2013 it increased to 0.38%. From these evolutions, we note that there are many fluctuations of the average of GDP per capita growth rate in OECD countries during the period of study. The share of environmentally related tax revenues in GDP also shows many fluctuations during the period of study. From the figure 1.1 and the figure 1.2, the following observations may be made: (i) environmentally related tax revenues as share of GDP show a rising trend over the period 1994 – 1999, increasing from 2.41% in 1994 to 2.61% in 1999. This rise in the aggregated measure comes mainly from the rise in the *energy, motor vehicle and transport, water and wastewater, waste management and other environmentally related tax revenues* share in GDP. In contrast, revenues from *ozone-depleting substances and mining and quarrying taxes* have decreased as share of the GDP in this period. (ii) During 2000 - 2001, environmentally related tax revenues as share of GDP decrease to reach 2.55% in 2001. (iii) Then it increased from 2.58% in 2002 until 2.62% in 2005. (iv) During the period from 2006 to 2008, it decreases sharply from 2.52% in 2006 until 2.38% in 2008. This decrease comes mainly from the decrease in the *energy, motor vehicle and transport, water and wastewater, waste management and other environmentally related taxes*. (iv) In 2009 - 2010, environmentally related tax revenues as share of GDP increase from 2.40% in 2009 to 2.47% in 2010. (iiiiv) During 2011-2013 it shows a decreasing trend, where it fell from 2.45% in 2011 to 2.44% in 2013. According to [OECD \(2006\)](#), there are about 375 environmentally related taxes in the OECD countries. The evolution of these taxes



Source: Authors’ calculations based on data from the World Bank and OECD database.

*Figure 1.1: Evolution of GDP per capita growth rate and total environmentally-related taxes revenues over time 1994 – 2013, OECD average (31 countries).*





Source: Author's calculations are based on data from the OECD database on Instruments used for Environmental Policy and Natural Resources Management.

*Figure 1.2: Evolution of different environmentally related taxes in the years between 1994 and 2013, OECD average (31 countries).*

has shown that the majority of revenue received comes from energy taxes and motor vehicle and transport taxes, whereas the rest constitute a small proportion of total environmentally related tax revenues.

## 1.4. Empirical strategy: model & data

### 1.4.1. Empirical economic growth model

In order to explore the nature of the relationship between aggregate environmentally related tax revenues and economic growth rate, we built a complete empirical growth model that controls the main drivers of economic growth according to the empirical and theoretical literature. The specification of this model is based on the Correlation Random Effects (CRE) approach, developed by [Wooldridge \(2010\)](#). The CRE model considers endogeneity as an unobserved heterogeneity problem without imposing any strict conditions or requiring any instruments ([Bache et al., 2013](#)). This method, as shown by [Wooldridge \(2010\)](#), is a reasonable way to deal with endogeneity and lagged effects within a small N dataset. It also has the advantage of allowing the estimation of time and country trends. The explanatory variables in this approach are separated into three principal categories, as follows:

$$gr_{it} = \emptyset\lambda_t + \theta Z_i + \delta W_{it} + \eta_i + \varepsilon_{it} \quad (1.1)$$

where  $gr_{it}$  indicates the annual percentage growth rate of GDP per capita in country  $i$  and year  $t$ ,  $\lambda_t$  is a vector of time dummies variables for years,  $Z_i$  is a set of time-constant observed variables;  $W_{it}$  represents a vector of control variables changing across countries and over time;  $\eta_i$  is the unobserved effects (heterogeneity) and  $\varepsilon_{it}$  indicates an error term. The (CRE) approach combines the fixed effects model, which assumes that there is a correlation between  $\eta_i$  and independent variables, with the random effects model, which supposes that the correlation between  $\eta_i$  and independent variables does not exist<sup>5</sup>. In particular, the (CRE) approach models the relationship between  $\{\eta_i\}$  and  $\{W_{it}\}$  allowing arbitrary correlation between them as follows<sup>6</sup>:

$$\eta_i = \Psi + \gamma\bar{W}_i + a_i \quad (1.2)$$

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<sup>5</sup> "...the crucial distinction between fixed and random effects is whether the unobserved individual effect embodies elements that are correlated with the regressors in the model, not whether these effects are stochastic or not" ([Greene, 2008: 183](#))

<sup>6</sup> The hypothesis used to model the correlation relationship between  $\eta_i$  and  $W_{it}$  is that: as  $\eta_i$  is, by definition, constant across time, it can be correlated by simple linear relationship with the average values of  $W_{it}$  across time ([Wooldridge, 2010](#))

Where  $\Psi$  is a constant,  $\bar{W}_i = T^{-1} \sum_{t=1}^T W_{it}$ ,  $a_i$  is a time-constant component and  $\text{Cov}(a_i, \bar{W}_i) = 0$ . By replacing (2) in (1), the CRE estimating equation becomes:

$$gr_{it} = \phi \lambda_t + \theta Z_i + \delta W_{it} + \Psi + \gamma \bar{W}_i + a_i + \varepsilon_{it} \quad (1.3)$$

The similarity between equation (1.3) and the equation of random effects model (RE) emerges from the hypothesis that  $a_i$  is uncorrelated with  $(W_{it})$ , whereas the equation (1.3) looks like the fixed effects model (FE) through including the time-constant variables ( $Z_i$ ). Many advantages can be achieved by using CRE model. Firstly, an international non-linear time trend in economic growth could be controlled by the term  $\lambda_t$ . This term takes into account international variations in economic growth that cannot be explained with the explanatory variables, but could however be correlated to them. For example, the 2001 and 2008 worldwide economic crises that affected growth may be partly estimated by these time dummies for years. Secondly, whereas the fixed effect model cannot estimate the effect of time-constant variables, the CRE model has the ability to measure their impact through the term ( $Z_i$ ). Thirdly,  $\bar{W}_i$  measures the influence of the average level of  $W_{it}$  on the dependent variable. This allows us, with respect to environmental tax policy, to take into account the systematic differences between countries achieving historically very high revenues of taxation and countries more moderate in their taxes revenues. These differences may have an impact on growth rate. Fourthly, the CRE regression is robust towards heteroscedasticity and serial correlation in  $\{\varepsilon_{it}\}$ . This robustness comes from a “cluster” option used in the command that estimates CRE equation in Stata software. This option produces consistent standard errors for linear panel models if the residuals are correlated within cluster (Hoechle et al., 2007). Finally, the (CRE) approach is based on a simple test in order to choose between the random effects or correlated random effects estimator. The estimations will be the usual random effects estimates, if  $\gamma = 0$ . *Variable Addition Test (VAT)* is used to test this hypothesis, where it examines whether the averages of the explanatory variables changing across the time are jointly equal to zero.

Consequently, the generic model that investigates the relationship between aggregate environmentally related tax revenues as a share of GDP and economic growth rate, in the short term, can be described as follows:

$$gr_{it} = \Psi + \beta_0 ETRT_{it} + \theta Z_i + \delta W_{it} + \gamma \bar{W}_i + \phi \lambda_t + \alpha_i + \varepsilon_{it} \quad (1.4)$$

Where  $ETRT_{it}$  denotes the share of environmentally related tax revenues in GDP. In order to explore this relationship in the long term, we re-estimate the equation (1.4) with lagged values of all explanatory variables for five periods, each period being one year. This method allows us to know whether the revenue generated from these taxes over the last years are correlated with economic growth rate in the current year. To examine whether this association depends on the level of revenue generated from environmentally related taxes itself or on its interaction with the initial level of GDP per capita, we allow ETRT to interact with itself, and with  $\ln Y_0$ . Therefore, the equation that answers the second question is as follows:

$$gr_{it} = \Psi + \beta_0 ETRT_{it} + \beta_1 (ETRT_{it} \times ETRT_{it}) + \beta_2 (ETRT_{it} \times \ln y_0) + \theta Z_i + \delta W_{it} + \gamma \bar{W}_i + \phi \lambda_t + \alpha_i + \varepsilon_{it} \quad (1.5)$$

Then we re-estimate the equation (1.5) with lagged values of all explanatory variables for five periods, each period being one year, in order to answer the second question in the long term.

Moreover, this paper also aims to investigate whether the relation between environmentally related tax revenues and economic growth differs between countries which have established environmental tax reforms (ETRs) and ones which have not. For this purpose, information about the implementation of ETRs in OECD countries in the examined period is collected through a literature review. We then used this information to build two groups of countries: countries which have implemented ETRs, and those which have not. After that, we applied the same empirical approach used in equation (1.4) on the two groups, with the intention of identifying possible differences in the relationships between environmentally related taxes and economic growth rate in both short and long term.

#### **1.4.2. Data**

Panel data was chosen to study the nature of the relation between environmentally related tax revenues and economic growth for two reasons: firstly, the available data about environmental taxation which ranges, according to OECD statistics, from 1994 to 2013 is not long enough for using time-series econometrics. Employing panel data will allow us to cover more observations and thus raise the statistical power and inference of the model. Secondly, [Temple](#)



(1999) and Baltagi (2001) argue that panel estimators are the most appropriate choices for growth regression.

The sample used is annual data covering the period 1994-2013 for 31 OECD countries; namely, Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom which are considered for this panel analysis. Because of completely missing patterns of data that concern productive expenditure variables for Chile, Mexico and USA, we excluded these countries from our sample. In addition, Latvia, which joined recently to the OECD, doesn't have data on environmentally related tax revenue. Therefore, it was excluded from the sample. The selection of the period was constrained by the availability of data about environmental tax revenues that are newly introduced in most OECD countries, and about other explanatory variables<sup>7</sup>. The data was extracted from various sources: (i) Government Finance Statistics (GFS) published by the International Monetary Fund (IMF); (ii) World Development Indicators (WDI) published by the World Bank; (iii) The Organization for Economic Co-operation and Development (OECD). Data on human capital stock are performed by the "Laboratoire d'Économie Appliquée au Développement (LEAD)" in Toulon University (France). Appendix (1.A) includes a summary of variables and data sources.

### **The dependent variable and the explanatory variables**

The dependent variable is the economic growth rate, measured as the annual percentage growth rate of GDP per capita based on purchasing power parity (PPP) at constant 2005 U.S. dollars. As far as the control variables are concerned, we considered a broad set of control variables typically used in the empirical and theoretical growth literature. We classified them in five categories as follows:

- *Environmental taxes*

According to Pigou (1920) *the optimal environmental tax* is the tax that equals between the marginal private benefit of emissions in production and the marginal social damage of emissions, while the international organizations define environmental tax as "a tax whose tax

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<sup>7</sup> The environmental tax revenues data provided by OCED statistics cover the 1994-2014 period. But as the data on capital human only run until 2013, we decided to restrict our study from 1994 to 2013.

base is a physical unit (or a proxy of it) that has a proven specific negative impact on the environment” (United Nations et al., 2003).

The measure of environmental tax revenue in this chapter is based on the United Nations definition which is accepted by the main international organizations, such as the OECD and the Statistical Office of the European Union (Eurostat). The environmental tax revenue data, which is provided by OECD statistics, is comprised of taxes on *energy products* such as fossil fuels, electricity and transport fuel (petrol and diesel). This includes all CO<sub>2</sub>-related taxes. Environmental tax revenue data also encompasses the *motor vehicle and transport taxes* which refer to one-off import or sales taxes on transport equipment, recurrent taxes on ownership, registration or road use of motor vehicles and other transport-related taxes (excluding transport fuel taxes). Recently, in 2016, new data concerning four categories of environmental tax revenues were added to OECD statistics. They are: (i) *ozone-depleting substances taxes*, such as chlorofluorocarbons (CFCs) and carbon tetrachloride; (ii) *water and wastewater taxes*, like taxes on water extraction, piped water, wastewater treatment; (iii) *waste management taxes*, for example, taxes on final disposal of solid waste, on packaging (e.g. plastic bags); and (v) *mining and quarrying taxes* which include mining royalties and excavation taxes (e.g. sand and gravel). The rest of environmentally related tax revenues that are not included elsewhere, e.g. hunting and fishing taxes, SO<sub>x</sub> and NO<sub>x</sub> emission taxes were classified in a category called *other taxes*. In this chapter, we used the total revenue of all environmentally related taxes as a proportion of GDP, extracted from OECD statistics, to investigate the relationship between environmental tax and economic growth rate. This variable is coded as (ETRT)

- *Conditioning variables*

Three variables, usually used in growth regressions literature as conditioning variables<sup>8</sup>, were selected to be included in this group of control variables: (i) the initial level of real GDP per capita measured by the natural logarithm of GDP per capita for each country in the year 1994. It is coded as  $lny_{i0}$ . The growth rate of real GDP per capita is related to the initial level of real GDP per capita in the standard growth model of Barro and Sala-i-Martin (2004). They predict that a country with a low level of initial income per capita relative to its own steady-state will tend to grow at faster rates than a country that is already close to its long-run potential level of steady-state. As this variable is constant over time, it has been included in the category  $Z_i$  of

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<sup>8</sup> The conditioning variables are the variables used in the Barro-type regressions (Kneller, et al., 1999)

equation (1.4). (ii) Total labor force growth rate (*TLF*). Population structure could influence economic growth through its impact on some determinants of growth such as investment and saving rate. (iii) Gross fixed capital formation as a percent of GDP was used to account for investment in physical capital. It is coded as (*k*). The annual change in physical capital (*change k*) was employed to capture the effect of physical capital accumulation which is considered as an engine of economic growth rate (Barro and Sala-i-Martin, 2004).

- *Human capital*

Human capital refers to “the knowledge, skills, competences and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being” (OECD 2001). On the connection between human capital and growth, the endogenous growth models predict that human capital could affect growth through two distinct channels. On the one hand, human capital might accelerate growth through the externalities that originate from an educated labor force which enhances the productivity of both labor and physical capital (Lucas Jr., 1988). On the other hand, human capital might affect growth mainly via innovation (Romer, 1986; Romer, 1990 and Aghion and Howitt, 1992)

In an empirical growth application like Baldacci et al. (2008) and Chi (2008), the level of human capital in the previous year ( $H_{t-1}$ ) and the annual changes of human capital (*change H*) are usually used to capture the effect of human capital on growth. Consequently, these two variables were employed to estimate the impact of human capital on economic growth rate in this model. We used the human-skill index, published by (LEAD) as a measure of human capital. Literacy rate, enrolment in tertiary education and mean years of schooling of adults were used to construct this index. As the data of this index is annual, the annual change of human capital could be included in the model, whereas this possibility is not available with the data of Barro and Lee (2013) which was constructed for a 5-year age group.

- *Fiscal variables*

With regard to the relation between (non-environmental) fiscal policy and growth, three variables have been selected to capture the impact of this policy: productive expenditure (*exp*), distortionary taxation (*tax*), and fiscal balance (*Balance*). The productive expenditure is defined as the sum of general government<sup>9</sup> spending on education, health, public order and safety, housing, and defense. All of which are measured relative to GDP. Following (Kneller

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<sup>9</sup> “General government consists of central government, state government, local government and social security funds” (OECD, 2013, pp 62)

et al, 1999; Adam and Bevan, 2005; Teles and Cesar Mussolini, 2014a, and Alcántar-Toledo and Venieris, 2014), these elements are considered as productive expenditure, because they are used in order to form physical and human capital and thus stimulate growth. The other government spending on social protection, economic services, recreation and culture as well as “unclassified” spending, were not included in the specification, because these categories of expenditure are considered growth neutral (Barro, 1990; Kneller et al., 1999; Teles and Cesar Mussolini, 2014a). We cited the data of productive expenditure mainly from OECD statistics and completed it from the Government Finance Statistics (GFS). The distortionary taxation was calculated as the sum of the taxes on income, profit and capital gains; payroll and workforce; as well as social security contributions as a percent of GDP. We consider these three measures of taxes as the main distortionary forms of taxation, because the revenue of environmentally related taxes, in most countries that have established environmental tax reform, has been used to reduce one or more of these three distortionary taxes. The presence of distortionary taxes in the model is very important when we study the effect of environmental taxation on the economy, because this reflects the level of pre-existing tax distortions (Bovenberg and de Mooij, 1994; Metcalf, 2000). As the non-distortionary taxation<sup>10</sup> (tax on domestic goods and services) is assumed to have negligible growth effects (Barro, 1990) and (Kneller et al., 1999), we didn't include it in the model.

The fiscal balance (surplus/deficit) “also referred to net lending (+) or net borrowing (-) of general government, is calculated as total general government revenues minus total general government expenditure. Revenues encompass social contributions, taxes other than social contributions, and grants and other revenues. Expenditure comprises intermediate consumption, compensation of employees, subsidies, social benefits, other current expenditure (including interest spending), capital transfers and other capital expenditure” (OECD, 2013, pp 62).

- *Macroeconomic control variables*

Basing on the literature of macroeconomic theory, we have chosen inflation rate and goods trade openness as macro control variables. The Inflation rate (INF) is measured by the annual

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<sup>10</sup> Our division of taxes into distortionary and non- distortionary taxes has been inspired from Barro (1990) who suggests that the effects of taxes on economic growth depend on whether tax is distortionary or non-distortionary. Distortionary tax is defined as the tax which has an impact on the saving/ investment decisions of agents and hence distorts the steady-state rate of growth. Whereas, Non-distortionary tax does not affect saving/ investment decisions and thus has no effect on growth rate.

percentage change in the Consumer Price Index. This variable is considered a proxy of macroeconomic stability. It is expected to have a negative relation with economic growth rate. Openness to international trade of goods (OPENG) is defined as (exports plus imports of goods) in percentage of GDP. It is a measure of the extent to which a country is linked to the rest of the world. In general, trade liberalization promotes economic performance and it is expected to be positively related to economic growth rate.

As we indicated in section (1.4.1), the expression  $W_{it}$  represents a vector of control variables varying across countries and over time. Therefore all the explanatory variables mentioned above (except  $\ln y_{i0}$ ) are included in the category  $W_{it}$  and their averages in the category  $\bar{W}$ , of equation (1.4). After identifying the variables used in this study and collecting their data, we used a multiple imputation (MI) procedure to treat missing data. Appendices (1.B and 1.C) provide the details about this procedure. Table (1.1) shows the descriptive statistics of the variables before and after the multiple imputation process. As the imputation of missing data is performed by using all the variables employed in this thesis, table (1.1) includes all these variables. The explanations of the rest of the variables used in this thesis will be presented in the second and the third chapter.

As already mentioned, information about the implementation of “revenue recycling system” was collected through a literature review. The reviewed literature includes articles published in academic journals, books, and policy reports. The “revenue recycling system” shows three types of ETRs in which the revenues from environmental taxes are used for reducing those on labor or capital, financing renewable energy investment projects or other environmental protection initiatives. A full list of the identified ETRs and a summary of some of their characteristics are presented in table (1.2). For each reform, the table provides the main sources of environmentally related tax revenue and the primary channels via which these revenues were recycled. In addition, it also shows when ETRs were introduced and the references from which relevant information was collected.

Variable	Before MI				After MI			
	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Gr	2.0656	3.1079	-14.5730	18.6211	2.0433	3.0543	-14.5598	13.0814
ETRT	2.5123	0.7398	0.2673	5.3856	2.5123	0.7392	0.2673	5.3856
lnY0	9.9078	0.7269	8.4973	10.9642	9.9078	0.7263	8.4973	10.9642
K	22.741	3.9980	11.7114	37.1010	22.7562	4.002	11.7114	37.1010
Change k	-0.08105	1.7551	-10.2458	10.9068	-0.0874	1.7592	-10.2458	10.9068
TLF	0.0093	0.0145	-0.0432	.120029	0.0093	0.0145	-0.0432	0.1200
H	0.8491	0.0644	0.6377	.9502	0.8491	0.0644	0.6377	.9502
Ht-1	0.8471	0.0647	0.6377	0.9502	0.8471	0.0647	0.6377	0.9502
Change H	0.0047	0.0111	-0.0155	0.0938	0.0047	0.0111	-0.0155	0.0938
Exp	15.2256	2.6214	7.9412	24.0129	15.0541	2.7108	4.0452	24.0129
Tax	21.6628	5.2969	6.78	34.969	21.6541	5.2802	6.78	34.969
Balance	-2.0096	4.5860	-32.3045	18.6959	-2.2141	4.6023	-32.3045	18.6959
INF	4.5271	9.6895	-4.4799	106.2627	4.5271	9.6818	-4.4799	106.2627
OPENG	67.6072	35.106	13.8653	181.4052	67.9476	35.2057	13.8653	181.4052
ET	233.6585	146.8462	11.9701	980.8488	232.7705	146.5881	11.9701	980.8488
DEBT	57.9122	36.8835	3.664	244.477	57.5186	36.5957	3.664	244.477
EINNOV	9.1407	3.81463	0	25.4	9.2552	3.71079	-0.2074	25.4
LCO2	11.5293	1.3908	7.7179	14.0929	11.5293	1.3896	7.7179	14.0929
DCPS	97.8268	50.6574	4.4165	311.063	98.3125	50.3945	4.4165	311.063
RQ	1.29396	0.41701	0.0309	2.0766	1.2783	0.4152	0.03	2.0766
GNS	23.3959	5.9636	3.247	41.689	23.3959	5.9588	3.247	41.689
FERT	1.64867	0.37641	1.076	3.05	1.6486	0.3761	1.076	3.05
TID	0.7232	0.10370	0.4831	0.9449	0.7232	0.1036	0.4831	0.9449
Y	33236.53	12858.03	10053.16	90628.36	33236.53	12847.76	10053.16	90628.36
TFCPEP_sh	76.8799	16.6601	22.3953	97.2401	76.8799	16.6468	22.3953	97.2401
LPop	16.21989	1.4427	12.4912	18.6679	16.2198	1.4416	12.4912	18.6679
ERGRDB	2.6805	1.98008	0.04669	17.6579	2.8592	2.2083	0.046	17.6579
FDI	5.1247	13.5981	-58.9776	253.4985	5.5952	14.1326	-58.9776	253.4985
RDPI	1.1520	0.49773	0.08682	2.4622	1.1918	0.5081	0.0868	2.4622

*Table 1.1: Descriptive statistics*

Country	year	Environmentally related taxes revenue	Revenue recycling system	References
<b>Australia</b>	2012	Introduction of a carbon pricing mechanism <sup>11</sup>	Reduction of income tax. Increase in pension allowances and in family benefits (lump sum transfer/year). Support for 'emissions intensive trade-exposed' industrial activities.	Withana et al. (2013)
<b>Austria</b>	2004	Introduction of a coal tax and increase of natural gas and mineral oil taxes.	Reduction of corporate taxes and tax incentives for SMEs. Reduction of personal income taxes for low and middle income households.	OECD (2007, 2009)
<b>Czech Republic</b>	1995	Increase of transport fuels tax.	Reduction of personal income tax and labor tax. Part of revenue is allocated to finance programs related to air pollution, including the reduction of emissions from smaller emission sources.	Ercolano, Gaeta, and Romano (2014) Withana et al. (2014)
	2008	New taxes on natural gas, coal and electricity.	Reduction of personal income tax and on social security contributions of employers and employees.	Ercolano, Gaeta, and Romano (2014)
<b>Denmark</b>	1994	Increase of energy taxes and introduction of taxes on tap water, wastewater tax, and plastic and paper bags.	Reduction of marginal income tax rates.	Andersen et al. (2007) Speck & Jilkova (2009)
	1996	Increase of industrial energy tax rates, and introduction of a Sulphur tax and a tax on natural gas.	Reduction of employers' social security contributions, subsidies for energy efficiency programs and support for SMEs <sup>12</sup> , Investment grants for energy saving measures.	Andersen et al. (2007) Speck & Jilkova (2009) Withana et al., (2013)
	1998	Increases of energy taxes (petrol, diesel, coal, and electricity, and natural gas, light and heavy fuel oil).	Reduction of personal income tax rates and taxes on the yield of pension savings.	Andersen et al. (2007) Speck & Jilkova (2009)
	2007	Yearly price indexation of energy taxes.	Reduction of personal income taxes.	Larsen (2011)
	2010	Increased taxes on energy and wastewater and changes in motor vehicle taxation.	Revenues from energy taxes help reduce healthcare payments and the lowest tax rate. Households also compensated by green checks (small tax deductions for every individual in the household).	Bragadóttir et al. (2014), Larsen (2011)
<b>Estonia</b>	2006	Increase of transport fuel taxes, introduction of a tax on natural gas and an electricity output tax.	Reduction of income tax rates. Increase in the tax-free allowance and tax exemptions for pensioners and families with more than two children. Part of revenue earmarked to finance environmental protection projects.	Ekins and Speck (2011) Withana et al. (2014)
<b>Finland</b>	1990	Introduction of a CO2 tax.	Reduction of personal income tax and social security contributions.	Bragadóttir et al. (2014), Withana et al. (2013),
	1997	Increase of CO2, Landfill tax.	Reduction of labor taxes.	Ercolano, et al. (2014)
	1998	Energy and environmental taxes.	Further reduction of labor taxes.	Andersen et al. (2007), Speck & Jilkova (2009)
<b>Germany</b>	1999	introduction of an electricity tax and Increase of existing energy taxes (heavy fuel oil, natural gas, light heating fuels, transport fuels)	Reduction of employers' and employees' social security (pension) contributions. Small fraction of revenue used for a program to promote renewable energy.	Andersen et al. (2007) Speck & Jilkova (2009), Withana et al. (2013)
	2006	Heating fuel tax on natural gas and heavy fuel oil.	Reduction of employers' and employees' social security (pension) contributions.	Withana et al., (2013)
<b>The Netherlands</b>	1996	Taxes on mineral oil products, natural gas and electricity; and taxes on water and waste disposal.	Reduction of corporate profit taxes, employers' social security contributions and income taxes. Part of revenue earmarked for energy premium system rewarding private households for the purchase of energy efficient appliances.	Andersen et al. (2007), Ruijs and Vollebergh (2013); Withana et al. (2013)

<sup>11</sup> For the first three years, the carbon price is fixed (i.e. carbon tax), before moving to an emission trading scheme in 2015 (Withana et al., 2013)

<sup>12</sup> SMEs refer to small and medium-sized enterprises.

	1999	Increase energy tax.	Reduction of income taxes and increase of tax-free allowances for SMEs. Reduction of employers' social security contributions, taxes for self-employed and corporate profit taxes.	Andersen et al. (2007), EEA (2011), Speck & Jilkova (2009)
<b>Norway</b>	1999	Taxes levied on CO <sub>2</sub> , SO <sub>2</sub> and diesel oil	Reductions in labor and capital income taxes. Reductions in employers' non-wage labor costs. New fund for climate change mitigation, renewable energy and energy conservation.	Hoerner & Bosquet (2001), OECD (2001), Withana et al., (2013)
<b>Sweden</b>	1991	Energy tax, CO <sub>2</sub> , SO <sub>2</sub> tax.	Reduction of personal income tax and social security contributions.	Ercolano, et al. (2014), EEA (2005)
	2001	Increase of taxes on CO <sub>2</sub> , motor vehicles, waste landfilling, gravel and pesticides.	Reduction of personal income taxes paid by medium and low-income households and social security contributions	Andersen et al. (2007), Eriksson et al. (2009), Speck & Jilkova (2009), EEA (2011); OECD (2014)
<b>Switzerland</b>	2008	Introduction of a CO <sub>2</sub> tax levied on fossil fuels, exempting transport fuels.	The revenues of the CO <sub>2</sub> tax recycled back to companies and households as a lump-sum. Taxes paid by enterprises redistributed to enterprises and taxes paid by citizens shared equally among citizens.	Ekins and Speck (2011)
<b>United Kingdom</b>	1996	Landfill tax.	Reduction of employers' insurance contributions. Part of revenue earmarked to energy efficiency improvements.	Ekins and Speck (2011) EEA (2005), Withana et al., (2013)
	2001	Climate change levy on energy products.	Reduction of employers' insurance contributions. Part of revenue earmarked to energy efficiency improvements.	Ekins and Speck (2011) EEA (2005), Withana et al., (2013)
	2002	Aggregates tax (sand, gravel, crushed rock)	Reduction of employers' insurance contributions. Part of revenue earmarked to energy efficiency improvements.	Ekins and Speck (2011) EEA (2005), Withana et al., (2013)

Note: Part of this table is based on Oueslati et al. (2017), pp 92-93.

*Table 1.2: ETRs in OECD countries*

To check the robustness of the model used in this chapter, firstly, using the QIC program, we verified whether certain or all the four categories of control explanatory variables<sup>13</sup> should be included in the CRE model. Appendix (1.D) shows this program. Secondly, in appendix (1.E), we employed the Variance Inflation Factor (VIF) test to verify the absence of multicollinearity. Finally, in appendix (1.F), panel unit root tests were used to demonstrate that the time series of economic growth rate (gr) and environmentally related tax revenues (ETRT) are stationary. We found that all four categories of control explanatory variables should be included in the CRE model, that there is no harmful multicollinearity, and that the time series of economic growth rate and environmentally related tax revenues are stationary.

<sup>13</sup> The four categories of explanatory variables are the variables that we have collected, in addition to environmental tax, as determinants of economic growth.



## 1.5. Results and Discussion

*Are the overall environmentally related tax revenues associated with the economic growth rate in the short and long term?*

Following the *Variable Addition Test (VAT)* for the equation 1.4, in the short and long term, (please see appendix (1.G) for the details of tests) we reject the null hypothesis in the short and long term, therefore  $\gamma \neq 0$ . Thus, all the models have correlated random effects estimates.

First, the estimation results provide information about the appropriate multiple imputation model. We can use the number of Largest FMI (Fraction of Missing Information), displayed in the last row of the table (1.3), to see if the specified number of imputations is sufficient for the analysis. The rule is that “ $M \geq 100 \times FMI$  provides an adequate level of reproducibility of MI analysis” (Stata Corp, 2013: 48). In our study, the largest FMI is 0.34 for equation (1.4) in the short term, and 0.15; 0.10; 0.13; 0.11; and 0.16 respectively for equation 1.4 in the long term. The number of imputations, 100, exceeds the required number of imputations: 34 (=  $100 \times 0.34$ ); 15 = ( $100 \times 0.15$ ); 10 = ( $100 \times 0.10$ ); 13 = ( $100 \times 0.13$ ); 11 = ( $100 \times 0.11$ ); 16 = ( $100 \times 0.16$ ). Therefore  $M = 100$  is sufficient for the analysis. Concerning the results associated with the analysis models, the estimation results of equation (1.4) are reported in table (1.3). Column (1) includes the results in the short term, whereas the columns from (2) to (6) show the results in the long term for five lagged periods, each period being one year. Estimation results revealed that there is no statistically significant relationship between the overall share of environmentally related tax revenues in GDP and economic growth rate in the short and long term. This result may be explained through discussing the following question: *Is this relationship sensitive to the level of revenue generated from environmentally related taxes or to the level of other variables in economy?* Table (1.4) reports estimation results of equation (1.5) which contains two interaction terms. The first is between ETRT and itself. The second is between ETRT and lnY0. The results reveal that when we allow these interactions to happen, the relationship between ETRT and gr becomes significant and negative in the short and the long term<sup>14</sup>. However, the results show that the first interaction

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<sup>14</sup> In order to know whether the significance of ETRT comes from its interaction with itself or with lnY0, we estimated equation (1.5) excluding the term (ETRT#lnY0), we found that the coefficient of ETRT becomes insignificant. This means that the significance of ETRT comes from its interaction with lnY0. The results of this estimation are available upon request.

term is statically insignificant, whereas the second is significant.

Variables	In the short term	In the long term				
	(1)	(2)	(3)	(4)	(5)	(6)
		<b>Lags=1</b>	<b>Lags=2</b>	<b>Lags=3</b>	<b>Lags=4</b>	<b>Lags=5</b>
ETRT	-0.518 (0.412)	-0.221 (0.272)	0.058 (0.328)	0.232 (0.410)	-0.117 (0.321)	0.140 (0.337)
lnY0	-0.017 (0.207)	0.010 (0.184)	-0.0003 (0.180)	0.068 (0.184)	0.190 (0.198)	0.140 (0.193)
Change k	<b>0.219*</b> (0.128)	<b>0.284***</b> (11.666)	0.035 (0.087)	0.073 (0.0715)	-0.008 (0.087)	0.034 (0.122)
TLF	8.975 (9.585)	3.223 (11.666)	<b>-18.733**</b> (8.391)	<b>-27.82***</b> (8.124)	-7.373 (11.916)	-17.283 (14.678)
Ht-1	4.413 (7.119)	-1.660 (8.967)	-0.131 (9.733)	2.652 (10.107)	-1.354 (12.314)	-4.714 (14.614)
ChangeH	<b>25.285**</b> (9.910)	<b>21.461***</b> (7.927)	-4.463 (15.928)	17.042 (12.025)	-17.036 (19.995)	14.640 (9.259)
exp	<b>-0.278***</b> (0.103)	-0.118 (0.079)	-0.059 (0.110)	-0.075 (0.137)	-0.161 (0.123)	<b>-0.176*</b> (0.100)
tax	-0.068 (0.099)	0.029 (0.09)	0.036 (0.105)	0.045 (0.105)	0.058 (0.101)	0.046 (0.101)
Balance	<b>0.080*</b> (0.044)	0.031 (0.037)	0.054 (0.041)	-0.027 (0.043)	-0.086 (0.058)	<b>-0.129**</b> (0.067)
INF	<b>-0.046***</b> (0.015)	<b>-0.053***</b> (0.011)	<b>-0.051***</b> (0.013)	<b>-0.060***</b> (0.015)	<b>-0.06***</b> (0.018)	-0.013 (0.021)
OPENG	<b>0.035**</b> (0.017)	<b>0.029**</b> (0.015)	0.013 (0.020)	0.011 (0.020)	0.014 (0.019)	0.017 (0.017)
Observations	589	554	520	485	449	411
Number of countries	31	31	31	31	31	31
Number of imputations	100	100	100	100	100	100
Largest FMI	0.34	0.15	0.10	0.13	0.11	0.16

Note: \*, \*\*, and \*\*\* indicates the significance level at 10, 5, and 1% respectively based on the two-tailed test. Standard error estimates are in parentheses. The dummy variables of time ( $\lambda_t$ ), the averages of the variables that change across the time ( $\bar{W}_t$ ) and a constant were included in the regressions but they are not presented in this table.

*Table 1.3: Regressions results of equation (1.4), in the short and long term*

*Dependent variable: Annual percentage growth rate of GDP per capita.*

We conclude that the effect of environmentally related taxes on economic growth rate is not sensitive to the level of revenues achieved itself but it is sensitive to the initial level of the country's richness. The results also show that the interaction term between ETRT and lnY0 has a positive sign, indicating that the increase in environmentally related tax revenues leads to an increase in the economic growth rate as the initial level of a country's GDP per capita rises. This finding makes us wonder about the marginal effects of ETRT on economic growth

rate for countries having different levels of initial GDP per capita. To answer this question, we calculate the average marginal effects of ETRT<sup>15</sup> at different quantiles of  $\ln Y_0$ , using “*mimrgns, dydx() at ()*” Stata command<sup>16</sup>. Table (1.5) shows the results of calculation. We find that the marginal effects of ETRT differ greatly between  $\ln Y_0$  levels. When the country has a low level of initial GDP per capita ( $\ln Y_0 = 8.863364$ ), the average marginal effects of ETRT on economic growth rate is negative in the short and long term. With the increasing level of  $\ln Y_0$ , the negative average marginal effects of ETRT decrease and they become positive when the country has a high level of initial GDP per capita ( $\ln Y_0 = 10.76395$ ), in the long term. These results allow us to propose a rule concerning the relationship between initial level of GDP per capita, environmental taxation and economic growth rate, which is: the higher the initial level of GDP per capita, the more environmentally related tax revenues can promote economic growth rate. This rule could be justified through two factors: First, assuming that environmentally-related taxes lead to higher prices, however, with higher level of GDP per capita, people have more discretionary income after paying for basic necessities; therefore, they have more ability and amenability to pay higher prices in return for better environmental quality. Second, economic development leads to a shift from farming to manufacturing which creates greater environmental degradation. However, increased productivity and rising real GDP per capita leads to a third shift from industry to the service sector. The service sector usually uses human capital more than physical capital. Consequently, introducing environmental tax, in countries depend in its growth on the service sector more than manufacturing and farming<sup>17</sup>, could reinforce economic growth due to three elements: (i) improving the productivity of human capital, which is the main engine of growth in these countries, across increasing people's health and their ability of learning, thanks to reducing pollution (Gradus and Smulders, 1993, 1996; Ewijk and Wijnbergen, 1994; Oueslati, 2002; Pautrel, 2008, 2009; Aloï and Tournemaine, 2011). (ii) Improving the quality of environment, due to reducing pollution, may reinforce tourism which is a principal component in the service sector. (iii) Rich countries have the ability to reduce the negative

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<sup>15</sup> As the coefficient of the interaction term (ETRT#ETRT) is not significant, we exclude it from the equation 1.5 when we calculate the average marginal effects of ETRT. This allows us to calculate the marginal effect of ETRT on economic growth rate taking into consideration only its interaction with  $\ln Y_0$ . In this case,  $\frac{\partial gr}{\partial ETRT} = \hat{\beta}_0 + \hat{\beta}_2 \times \ln Y_0$ .

<sup>16</sup> For more information about the average marginal effects at specific values of explanatory variables see Williams (2012)

<sup>17</sup> See appendix (1.H)

effect of environmental taxation on physical capital through improved technology and higher productivity.

Variables	In the short term	In the long term				
	(1)	(2)	(3)	(4)	(5)	(6)
		Lags=1	Lags=2	Lags=3	Lags=4	Lags=5
ETRT	<b>-8.074**</b> (3.804)	<b>-4.802*</b> (2.631)	-2.589 (2.640)	-1.154 (3.391)	<b>-4.386*</b> (2.713)	<b>-6.155***</b> (2.369)
ETRT#ETRT	-0.049 (0.171)	0.019 (0.139)	0.018 (0.154)	-0.077 (0.152)	-0.234 (0.119)	-0.230 (0.147)
lnY0	<b>-1.899**</b> (0.953)	-1.069 (0.668)	-0.615 (0.700)	-0.317 (0.839)	-1.039 (0.661)	<b>-1.544***</b> (0.586)
ETRT#lnY0	<b>0.763**</b> (0.365)	<b>0.438*</b> (0.249)	0.249 (0.277)	0.170 (0.357)	<b>0.519*</b> (0.282)	<b>0.703***</b> (0.246)
Change k	<b>0.214*</b> (0.124)	<b>0.277***</b> (0.065)	0.031 (0.089)	0.070 (0.075)	-0.016 (0.089)	0.040 (0.119)
TLF	10.845 (9.647)	4.681 (11.350)	<b>-17.963**</b> (7.915)	<b>-27.40***</b> (8.027)	-6.158 (12.132)	-14.422 (14.402)
Ht-1	6.178 (7.473)	-0.599 (9.098)	0.443 (9.916)	2.786 (10.444)	-1.300 (12.781)	-5.427 (15.030)
Change H	<b>25.736***</b> (10.075)	<b>21.596***</b> (7.992)	-4.374 (16.015)	17.228 (11.893)	-16.852 (20.009)	13.819 (9.252)
exp	<b>-0.282**</b> (0.103)	-0.119 (0.081)	-0.061 (0.112)	-0.078 (0.138)	-0.175 (0.125)	<b>-0.192*</b> (0.102)
tax	-0.105 (0.108)	0.006 (0.092)	0.024 (0.102)	0.037 (0.104)	0.036 (0.101)	0.019 (0.099)
Balance	0.071 (0.048)	0.025 (0.038)	0.0515 (0.042)	-0.030 (0.043)	<b>-0.097*</b> (0.055)	<b>-0.149**</b> (0.066)
INF	<b>-0.047***</b> (0.014)	<b>-0.053***</b> (0.012)	<b>-0.051***</b> (0.013)	<b>-0.061***</b> (0.0164)	<b>-0.071***</b> (0.020)	-0.021 (0.022)
OPENG	<b>0.037**</b> (0.016)	<b>0.030**</b> (0.015)	0.013 (0.020)	0.012 (0.021)	0.017 (0.019)	0.022 (0.017)
Observations	589	554	520	485	449	411
Number of countries	31	31	31	31	31	31
Number of imputations	100	100	100	100	100	100
<b>Largest FMI</b>	<b>0.36</b>	<b>0.17</b>	<b>0.25</b>	<b>0.31</b>	<b>0.11</b>	<b>0.15</b>

Note: \*, \*\*, and \*\*\* indicates the significance level at 10, 5, and 1% respectively based on the two-tailed test.

Standard error estimates are in parentheses. The dummy variables of time ( $\lambda_t$ ), the averages of the variables that change across the time ( $\bar{W}_i$ ), and a constant were included in the regressions but they are not presented here.

*Table 1.4: Regressions results of equation (1.5), in the short and long term*

*Dependent variable: Annual percentage growth rate of GDP per capita.*

		Short term	Long term				
			Lags=1	Lags=2	Lags=3	Lags=4	Lags=5
Quantile	lnY0 value	dgr\d(ETRT)	dgr\d(ETRT)	dgr\d(ETRT)	dgr\d(ETRT)	dgr\d(ETRT)	dgr\d(ETRT)
<b>P(10)</b>	8.863364	-1.484**	-0.702	-0.232	0.065	-0.620	-0.760
<b>P(25)</b>	9.339503	-1.143**	-0.533	-0.131	0.122	-0.459	0.008
<b>P(50)</b>	10.18427	-0.537	-0.233	0.047	0.223	-0.171	0.008
<b>P(75)</b>	10.38708	-0.392	-0.161	0.090	0.248	-0.103	0.126
<b>P(90)</b>	10.76395	-0.121	-0.027	0.169	0.293	0.025	0.346

Note: \*, \*\*, and \*\*\* indicates the significance level at 10, 5, and 1% respectively.

*Table 1.5: The average marginal effects of ETRT at different quantiles of lnY0 in the short and long term*

With respect to control variables and in order to know which equation we should use to interpret the findings, we ran the QIC program for equations 1.4 and 1.5. The best fitting model is the one that has the smallest value of the average of *QIC* (Cui and others, 2007). Table (1.6) reports the descriptive statistics of QIC values. The best equation to interpret the results is the equation 1.5 which has the least value of the mean of QIC (229490.6).

Variable	Obs	Mean	Std. Dev.	Min	Max
<b>QICeq4</b>	100	236990.5	472.0661	236384.2	239105.3
<b>QICeq5</b>	100	229490.6	570.9566	228643.6	230901

Source: Author's calculations

*Table 1.6: The descriptive statistics of the values of QIC for equation (1.4) and (1.5)*

At the beginning, the discussion will focus on the results obtained in the short term, then will continue to discuss those concerning the long term. In the short term, estimation results broadly confirm expectations about the relationship between the control variables and economic growth rate. The analysis reveals that annual change in physical capital, annual change in human capital and openness to international trade of goods are positively associated with economic growth rate. In contrast, the natural logarithm of initial value of country's GDP per capita, the productive expenditure and inflation rate are inversely related to economic growth rate. The total labor force growth rates, the level of human capital in

previous year, as well as distortionary taxation do not seem to have a statistically significant relationship with economic growth rate. In the long term, column (6) shows a negative correlation between  $\ln Y_0$  and economic growth rates. This result corresponds to expectations of [Barro and Sala-i-Martin \(2004\)](#) about the *convergence effect*.

The annual change of physical capital, in column (2), appears to be positively associated with economic growth rate. This is in line with the endogenous growth theory assumptions which consider the accumulation of physical capital as an engine of economic growth rate in the long-term. The columns (3) and (4) indicate that *TLF* have a negative association with economic growth rate. This could be due to the very stable nature of the labor force across the OECD countries, relative to that in developing economies. We can see that clearly in the table of descriptive statistics where (on average) the annual growth rate of total labor force is 0.009 percent, and its minimum value is - 0.04, whereas the maximum value is only 0.12. The results from column (2) show that the variable that has the largest magnitude of positive relationship with growth rate is *Change H*. An increase of annual change in human capital by 0.01 point is associated with 21.596 percent increase in the economic growth rate when the number of lagged values equals to one. This can be explained by the dominance of the services sector, which depends mainly on human capital, on the total output of developed countries. We can see this in appendix (1.H). Beginning in 1995, the value added in the service sector represents, on average, more than 60% of GDP in our sample of OECD countries. The productive expenditure appears to be negatively associated with economic growth rate, in column (6). This can be explained by two factors: inefficient use of money ([Alesina et al., 2002](#)) and/ or “resource displacement” ([Ramey, 2011](#)). When the government spends money, it uses labor and/or capital and those resources no longer are available for private sector uses. The coefficient associated with *Balance* is negatively correlated with growth rate when the values of variables are lagged to four and five years. This could be due to the high level of deficit, which reaches -32.30 percent of GDP in some OECD countries (please see descriptive statistics of variables in table 2). Finally, the coefficient of *INF* is negatively correlated to the economic growth rate during the first four periods of lagged values for explanatory variables, whereas *OPENG* has a positive association with economic growth rate only when the number of lagged periods equals to one.

Now, we present in the table (1.7) a comparison between the results obtained before and after imputing missing data in the short term.

Variables	Before imputation		After imputation	
	(1)	(2)	(1)	(2)
ETRT	-0.6184 (0.577)	<b>-13.91**</b> (3.444)	-0.518 (0.412)	<b>-8.074**</b> (3.804)
ETRT#ETRT		-0.5408 (0.129)		-0.049 (0.171)
lnY0	0.113 (0.229)	<b>-3.883***</b> (0.972)	-0.017 (0.207)	<b>-1.899**</b> (0.953)
ETRT#lnY0		<b>1.616**</b> (0.358)		<b>0.763**</b> (0.365)
Change k	<b>0.209</b> (0.156)	<b>0.197</b> (0.153)	<b>0.219*</b> (0.128)	<b>0.214*</b> (0.124)
TLF	24.972 (9.585)	26.2809 (9.970)	8.975 (9.585)	10.845 (9.647)
Ht-1	<b>17.318***</b> (6.352)	<b>17.205***</b> (6.607)	4.413 (7.119)	6.178 (7.473)
Change H	<b>23.845**</b> (9.941)	<b>23.954**</b> (10.498)	<b>25.285**</b> (9.910)	<b>25.736***</b> (10.075)
exp	<b>-0.193**</b> (0.103)	<b>-0.202**</b> (0.087)	<b>-0.278***</b> (0.103)	<b>-0.282**</b> (0.103)
tax	-0.130 (0.100)	-0.098 (0.097)	-0.068 (0.099)	-0.105 (0.108)
Balance	<b>0.067</b> (0.053)	0.067 (0.053)	<b>0.080*</b> (0.044)	0.071 (0.048)
INF	<b>-0.013</b> (0.058)	<b>-0.0008</b> (0.051)	<b>-0.046***</b> (0.015)	<b>-0.047***</b> (0.014)
OPENG	<b>0.041**</b> (0.017)	<b>0.046***</b> (0.014)	<b>0.035**</b> (0.017)	<b>0.037**</b> (0.016)
Observations	509	509	589	589
Number of countries	31	31	31	31

Note: \*, \*\*, and \*\*\* indicates the significance level at 10, 5, and 1% respectively based on the two-tailed test. Standard error estimates are in parentheses. The dummy variables of time ( $\lambda_t$ ), the averages of the variables that change across the time ( $\bar{W}_i$ ), and a constant were included in the regressions but they are not presented here.

*Table 1.7: Regressions results of equations (1.4) and (1.5), before and after multiple imputation process, in the short term.*

*Dependent variable: Annual percentage growth rate of GDP per capita.*

The column (1) and (2) show the estimated results of equation (1.4) and (1.5) respectively. We found that the coefficients of the annual change in gross fixed capital formation (change k) and of inflation rate (INF) lose their significant when the incomplete database was used to estimate the equations (1.4) and (1.5). In addition, the association between the fiscal balance (Balance) and economic growth rate becomes insignificant when the equation (1.4) was

estimated with missing data. This difference in findings can be explained as follows: when the sample contains missing values, the list-wise deletion - a method used by most statistical packages for handling missing data - removes any row that contains a missing value from the analysis (Honaker, King, and Blackwell 2011a). Since statistical power relies partly on a large sample size, list-wise deletion will reduce the statistical power of the tests conducted (Olinsky, Chen, and Harlow 2003), which is the reason why the results were less significant with the reduced database (15.7% reduction in size of the database). On the other side, when the multiple imputation process was run on our incomplete data, the size of the sample and the statistical power of the test increased, allowing us to observe more significant effects. Thus we can say that the imputation improved data quality and contributed to obtaining reliable estimates.

*Does the relationship between overall environmentally related tax revenues and the economic growth rate differ between the countries which have implemented ETRs and those which have not?*

Tables (1.8) and (1.9) show the results in the short and long term of the equation 1.4 when it is estimated on two samples; a sample containing the 12 countries which have established “revenue recycling system” in the examined period and a sample including the other 19 countries. The estimation results reveal notable differences between the two groups of countries. The association between environmentally related tax revenues and economic growth rate, in the short and long term, is statistically insignificant in the countries which have not implemented ETRs, whereas this association is statistically significant and negative in the countries which have implemented ETRs<sup>18</sup>. These results do not lend themselves as evidence of a negative effect of “revenue recycling system” on the relationship between economic growth rate and environmentally related tax revenues. They only show that there is a significant difference in this relationship between countries which have and countries which have not implemented ETRs. We think that the changes in distortionary taxes structure, energy efficiency improvements, and environmental protection projects due to the use of environmentally related tax revenues may have given a role more important of ETRT effect on economic growth in the countries that have implemented ETRs compared with those that have not.

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<sup>18</sup> In the long term, the association between environmentally related taxes revenue and economic growth rate is statistically significant and negative when the number of lagged period equals to one, three and four.



Variables	Countries without revenue recycling	Countries with revenue recycling
ETRT	-0.280 (0.379)	<b>-1.916**</b> (0.820)
lnY0	-0.079 (0.299)	<b>0.980**</b> (2.064)
Change k	0.061 (0.085)	<b>0.635***</b> (0.210)
TLF	10.410 (11.510)	16.666 (16.400)
Ht-1	4.077 (14.228)	9.310 (5.947)
Change H	<b>33.559**</b> (15.184)	7.465 (10.816)
exp	-0.355 (0.223)	<b>-0.228***</b> (0.044)
tax	-0.088 (0.144)	0.024 (0.180)
Balance	<b>0.126*</b> (0.067)	-0.048 (0.067)
INF	<b>-0.046***</b> (0.018)	-0.002 (0.076)
OPENG	0.024 (0.022)	<b>0.067***</b> (0.020)
Observations	361	228
Number of countries	19	12
Number of imputations	100	100
Largest FMI	0.41	0.60

Note: \*, \*\*, and \*\*\* indicates the significance level at 10, 5, and 1% respectively based on the two-tailed test. Standard error estimates are in parentheses. The dummy variables of time ( $\lambda_t$ ), the averages of the variables that change across the time ( $\bar{W}_i$ ), and a constant were included in the regressions but they are not presented in this table.

*Table 1.8: Regression results of Eq.1.4 in the short term for countries that have implemented ETRs and those that have not*

*Dependent variable: Annual percentage growth rate of GDP per capita.*

Variables	Countries without revenue recycling					Countries with revenue recycling				
	Lags=1	Lags=2	Lags=3	Lags=4	Lags=5	Lags=1	Lags=2	Lags=3	Lags=4	Lags=5
ETRT	0.044 (0.38)	0.244 (0.501)	0.543 (0.626)	0.043 (0.360)	0.187 (0.455)	<b>-1.326***</b> (0.430)	<b>-1.216*</b> (0.649)	<b>-1.648**</b> (0.821)	<b>-1.137*</b> (0.690)	-0.831 (0.757)
lnY0	-0.122 (0.304)	-0.262 (0.284)	-0.239 (0.274)	-0.082 (0.277)	0.056 (0.313)	<b>0.830***</b> (0.231)	<b>1.253***</b> (16.070)	0.415 (5.104)	0.404 (0.651)	0.489 (0.396)
Change k	<b>0.328***</b> (0.087)	<b>0.185**</b> (0.082)	<b>0.164**</b> (0.056)	-0.046 (0.110)	-0.058 (0.126)	<b>0.218*</b> (0.127)	<b>-0.315***</b> (0.113)	<b>-0.272*</b> (0.146)	0.098 (0.134)	<b>0.311**</b> (0.148)
TLF	5.506 (13.615)	-15.574 (9.980)	<b>-29.76***</b> (10.740)	-14.592 (13.272)	-9.781 (17.641)	-3.357 (16.019)	-22.264 (15.141)	-26.265 (17.093)	12.969 (20.077)	-24.061 (25.680)
Ht-1	-12.123 (16.618)	-7.613 (17.152)	-1.415 (17.725)	-7.362 (18.292)	-7.927 (19.031)	12.910 (8.862)	17.772 (12.487)	14.752 (13.539)	7.838 (14.070)	-0.269 (16.266)
Change H	16.038 (12.337)	-23.214 (28.832)	13.943 (16.142)	-26.576 (30.206)	5.368 (14.851)	<b>27.454***</b> (9.242)	<b>16.932*</b> (10.341)	29.385 (27.010)	1.938 (36.313)	<b>18.997**</b> (9.005)
exp	-0.004 (0.204)	-0.026 (0.229)	-0.050 (0.293)	-0.252 (0.256)	-0.290 (0.278)	<b>-0.238***</b> (.058)	<b>-0.190***</b> (0.046)	<b>-0.188***</b> (0.069)	-0.106 (0.124)	<b>-0.112*</b> (0.060)
tax	-0.023 (0.146)	-0.067 (0.141)	-0.044 (0.146)	0.069 (0.165)	0.050 (0.134)	0.139 (0.166)	0.265 (0.164)	0.261 (0.179)	0.256 (0.186)	0.102 (0.161)
Balance	0.020 (0.042)	0.047 (0.051)	-0.031 (0.055)	-0.063 (0.081)	-0.144 (0.098)	-0.057 (0.116)	<b>-0.106*</b> (0.059)	<b>-0.132***</b> (0.027)	<b>-0.222**</b> (0.115)	-0.261 (0.164)
INF	<b>-0.051***</b> (0.013)	<b>-0.049***</b> (0.018)	<b>-0.051*</b> (0.019)	<b>-0.069***</b> (0.020)	<b>-0.035*</b> (0.019)	-0.101 (0.074)	<b>-0.116**</b> (0.053)	<b>-0.233**</b> (0.097)	-0.062 (0.043)	<b>-0.178*</b> (0.059)
OPENG	0.034 (0.022)	0.017 (0.027)	0.017 (0.026)	0.016 (0.024)	0.011 (0.017)	0.022 (0.019)	0.024 (0.017)	<b>0.024*</b> (0.014)	0.012 (0.016)	0.039 (0.030)
Observations	339	320	298	276	251	215	200	187	173	160
Number of countries	19	19	19	19	19	12	12	12	12	12
Number of imputations	100	100	100	100	100	100	100	100	100	100
Largest FMI	0.16	0.15	0.18	0.16	0.16	0.32	0.32	0.31	0.27	0.15

Note: \*, \*\*, and \*\*\* indicates the significance level at 10, 5, and 1% respectively based on the two-tailed test. Standard error estimates are in parentheses. The dummy variables of time ( $\lambda_t$ ), the averages of the variables that change across the time ( $\bar{W}_i$ ), and a constant were included in the regressions but they are not presented in this table.

*Table 1.9: Regression results of Eq.1.4 in the long term for countries that have implemented ETRs and those that have not*

*Dependent variable: Annual percentage growth rate of GDP per capita*

## 1.6. Conclusion

In this chapter we have provided empirical evidence of the macroeconomic relationship between environmentally related tax revenues and economic growth rate in the short and long term. The analysis also investigates whether this relationship differs between countries which have implemented environmental tax reforms and those which have not. In order to complete an un-balanced data set of 31 OECD countries from 1994 to 2013, multiple imputation method with an Expectation Maximization Bootstrapped algorithm was implemented,

improving data quality and inferences validity. In addition, information about the implementation of ETRs in the examined period is collected through a review of policy literature. The Correlated Random Effects (CRE) panel data model developed by [Wooldridge \(2010\)](#) was employed to estimate the effects. Empirical results reveal that there is no statistically significant relationship between the overall share of environmentally related tax revenues in GDP and economic growth rate in the short and long term. However, when we allow ETRT to interact with  $\ln Y_0$ , this relationship becomes significant and negative reflecting the importance of a country's richness level in determining the nature of this relationship. Furthermore, we found that, the higher the initial level of GDP per capita, the more environmentally related tax revenues can promote economic growth rate. We believe that these results could be insightful to policymakers. Governments seeking to introduce environmentally related taxes or planning to increase these taxes in order to curb emissions, should take into consideration the initial level of GDP per capita in order to promote economic growth rate. More precisely, introducing environmentally related taxes in countries having a low level of initial GDP per capita will damage the economic growth rate, while these taxes could promote the economic growth rate when the initial level of GDP per capita is high. Our results reveal also that the relationship between environmentally related tax revenues and economic growth rate varies if there is a mechanism to redistribute the revenues generated from these taxes. In countries where such mechanisms are present, the association between environmentally related tax revenues and economic growth rate is statistically significant and negative in the short and long term. On the contrary, no significant association is identified between these variables when such mechanisms are absent.

## 2. Chapter 2: Exploring the link between energy based taxes and economic growth

### Abstract

This chapter provides a new approach to measure energy taxes. Then, this measure was used to investigate the relationship between energy based taxes and economic growth rate. The analysis was based on a panel dataset of 31 OECD countries from 1994 to 2013. Using the Correlated Random Effects (CRE) panel data model, we found that interacting with other variables in the economy, energy based taxes are negatively associated with economic growth rate in the short and long term. This association may rely significantly on the level of the economy's dependence on polluting energy use as a share of total energy used in the production process in the short and long run, and on the commercial trade openness only in the long run. In addition, the study showed that an increase in energy based taxes can enhance significantly the economic growth rate, as the initial level of country's richness increases.

### 2.1. Introduction

How environmental taxation affects economic growth is a central and controversial issue in environmental economics. Although the literature is quite abundant on the subject, it is worth noting, as we saw in the literature review of the first chapter, that most contributions are theoretical and do not lead to a consensus on the short- and long-term effects of environmental taxes on economic growth. The lack of structured data on environmental taxation may explain the scarcity of empirical studies on the subject. The data provided by the OECD contains only statistics about the revenue generated from environmentally related taxes but not about their rates. These revenues are measured in four units: millions of USD, a share of total tax revenues, per capita, and percent of GDP. However, these methods of measurement consider the revenue from taxes without taking into account the variations in the tax base. This may weaken the role that environmental taxation can play in the economy and does not reflect its real impact on the economic variables. In this chapter, we propose an alternative approach taking into account not only the revenue generated but also the variations in the tax base. Environmentally related taxes include seven categories: *energy*; *motor*

*vehicles and transport; ozone-depleting substances; water and wastewater; waste management; mining and quarrying, and other environmentally related taxes.* This implies that environmentally related taxes are imposed on different tax bases. Therefore, it is difficult to construct a common base for these factors. For this reason and in order to apply our new approach, we focus our analysis on the most important category among them: energy taxes (see section 2.2). The total final consumption of polluting energy products is considered as a base of these taxes. Therefore, the proxy that we construct to measure energy taxes is calculated as follows: energy taxes revenues measured in millions American dollars divided by the total final consumption of polluting energy products measured in ton of oil equivalent. This proxy is then used to achieve two objectives: First, examining the nature of the relation between energy taxes and economic growth rate in the short and long term. The second objective is to test whether the effect of energy taxes on the economic growth rate is sensitive to the level of other variables, such as: the initial level of a country's richness, polluting energy use (as internal factors in the economy) and commercial openness of goods (as external factor in the economy).

The novelty in this chapter lies in three aspects. First, we propose a new approach to measure energy taxes. This approach showed more ability to capture the effect of energy taxes on economic growth than the measurements provided by the OECD statistics. Second, we provide the first empirical evidence on the sensibility of the effects of energy taxes on economic growth rate for the level of other variables in the economy in the short and long term. Third, the analysis is based on a balanced dataset for a large sample of OECD countries, where the multiple imputation method was used in order to complete the missing data. This method has improved data quality and inferences validity.

The rest of the chapter is organized as follows. Section 2.2 lays out the motivation for this study by providing an overview of trends in energy taxes revenues, total final consumption of polluting energy products, and GDP per capita growth rate in OECD countries over the last two decades. Section 2.3 presents the empirical model. Section 2.4 describes the data used. In sections 2.5, we discuss the empirical results on a short and long term basis. The last section concludes the chapter by summarizing the main findings.

## 2.2. Trends in OECD countries

Data on energy tax revenues are taken from the OECD database on “Instruments used for Environmental Policy and Natural Resources Management”<sup>2</sup>. Energy taxes can be broadly defined as compulsory, unrequited payments to general government levied on energy products (OECD, 2001). Compared to other tax revenues, the revenues raised by energy taxes are the most important among environmentally related taxes over the period (1994 – 2013) (see figure 2.1).

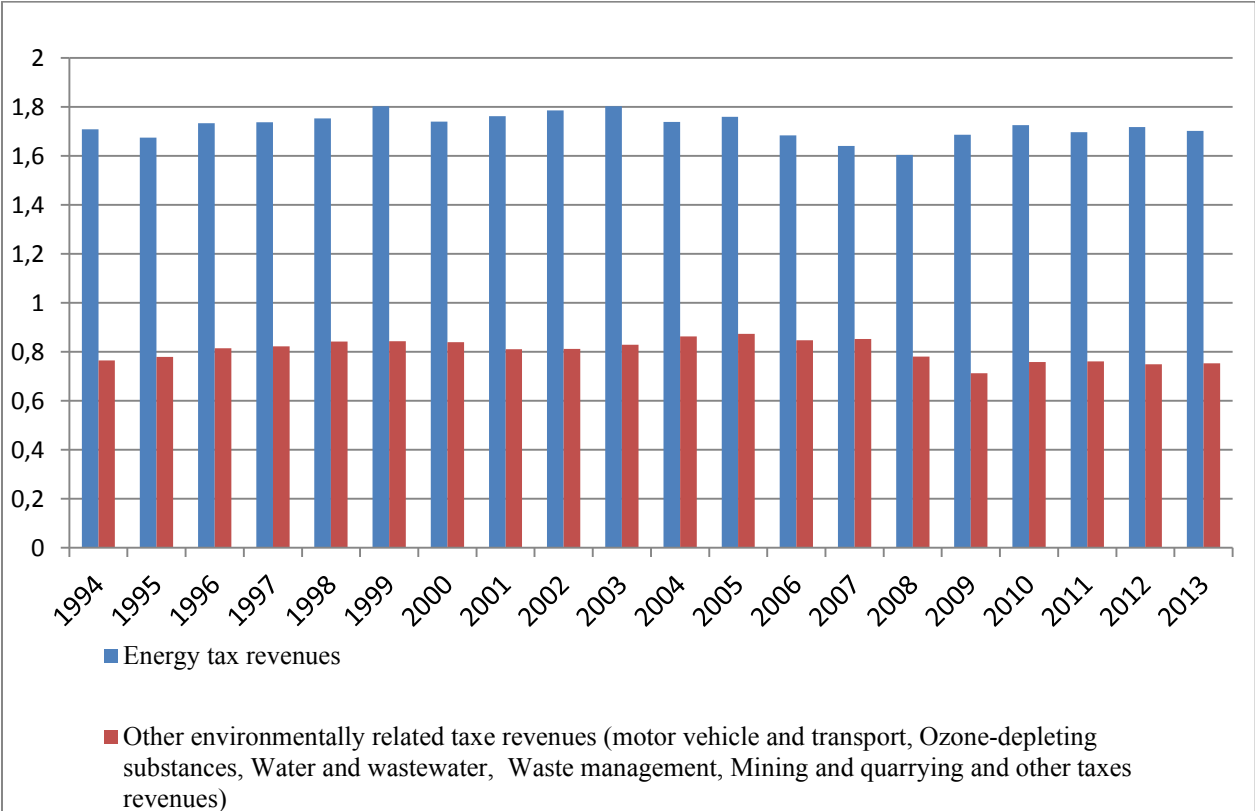


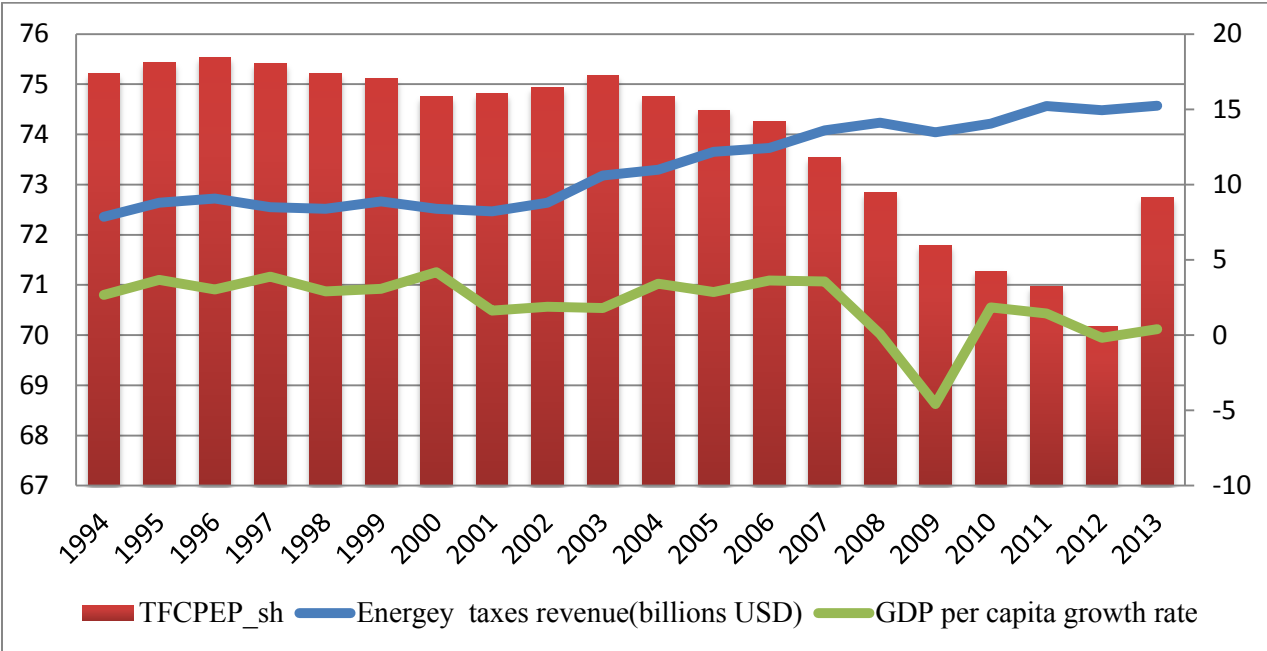
Figure 2.1: Development of different environmentally-related tax revenues as a % of total tax revenue over time, OECD average (31 countries)<sup>19</sup>

Figure (2.2) shows the evolution of the OECD average of energy tax revenues measured in billions United States Dollars (USD), the share of total final consumption of polluting energy products<sup>20</sup> in total final consumption of energy (in %) (TFCPEP\_sh) and GDP per capita growth rate over the period of study (1994 – 2013).

<sup>19</sup> Our sample includes 31 OECD member countries. Chile, Mexico and the USA were excluded because there was no data for the productive expenditure variable. We explain this in the section 1.4.2 of chapter 1.

<sup>20</sup> The definition of this variable exists in the section 2.4.

On average, the energy tax revenues show a slow rising trend over the period 1994 – 1996, and then it continues without showing great changes over the period 1997-2001. In 2002, energy tax revenues are starting to take an upward trend until 2008. It increased from 8.2 billion in 2001 to 14.11 billion in 2008. After that, it decreased to 13.4 billion in 2009. Then it restarts an increasing trend between 2010 and 2013. In general, revenues of energy taxes measured in billions USD had an increasing trend from 2002 (8.2 billion) until the end of study period (15. 22 billion). This trend was accompanied by a reduction in (TFCPEP\_sh) which decreased from 75.17% in 2003 to 70.17% in 2012, while it maintained almost the same level over the period 1994 - 2002. This implies that there was an expansion in the types of energy taxes imposed or an increasing in their rates over the period 2002-2012. The average GDP per capita growth rate shows many fluctuations during the period of study with a rising trend appearing from 1994 to 2000 and reaching 4.18% in 2000, from which it declined from 2001 to 2003 and stabilized at 1.8% in 2003. After that, we can see an increase to 3.57% percent in 2007, falling sharply in 2008 to stabilize at - 4.57% in 2009, to due to the latest world financial crisis in the U.S.A. In 2010 it recovered, but once again decreased to - 0.17% in 2012. In 2013 it increased to 0.38.



*Figure 2.2: Evolution of energy taxes revenues, total final consumption of polluting energy products and GDP per capita growth rate over the time, OCDE average (31 countries), 1994– 2013.*

### 2.3. Empirical model

In order to explore the link between economic growth rate and energy based taxes, the equation of GDP per capita growth rate,  $g$ , is assumed to take the following form:

$$g = f(ET, \zeta, H, X, \Omega,)$$

Where  $ET$  represents a proxy of energy taxes,  $\zeta$  are the conditioning variables;  $H$  represents human capital;  $X$  refers to fiscal variables;  $\Omega$  is a vector of other macroeconomic variables. With this equation, we consider variables that are considered to have a significant effect on economic growth rate, according to the empirical growth literature. In order to know more about the justification of control variables, please see section 1.4.2 in chapter 1. The baseline specification of the growth equation is based on the Correlation Random Effects (CRE) approach, developed by (Wooldridge 2010). As it was shown in the first chapter, the structure of this model takes the following form:

$$gr_{it} = \theta Z_i + \delta W_{it} + \phi \lambda_t + \Psi + \gamma \bar{W}_i + a_i + \varepsilon_{it} \quad (2.1)$$

where subscript  $i$  indicates country  $i$ ; subscripts  $t$  indicate year,  $gr_{it}$  is the annual percentage growth rate of GDP<sup>21</sup> per capita in country  $i$  and year  $t$ ,  $Z_i$  is a set of time-constant observed variables;  $W_{it}$  denotes the variables that change across the country( $i$ ) and the time ( $t$ );  $\lambda_t$  is a vector of aggregate time effects (time dummies for years);  $\Psi$  is a constant;  $\bar{W}_i = T^{-1} \sum_{t=1}^T W_{it}$ ;  $a_i$  is a time-constant component and  $\varepsilon_{it}$  indicates an error term.

Consequently, the baseline specification of the growth model is described in equation (2.2).

$$gr_{it} = \Psi + \beta_0 ET_{it} + \theta Z_i + \delta W_{it} + \gamma \bar{W}_i + a_i + \phi \lambda_t + \varepsilon_{it} \quad (2.2)$$

Where  $ET_{it}$  refers to the proxy of energy taxes. It is defined as the total revenues from energy taxes divided by the total final consumption of coal and coal products, oil products, natural gas and polluting electricity. It measures tax revenue from energy taxes per unit of fossil fuel energy use, in US \$ per ton of oil equivalent. More details about this proxy will be presented by the section 2.4. The other explanatory variables are as follows:

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<sup>21</sup> “Gross domestic product (GDP) is the standard measure of the value of goods and services produced by a country during a period”(OECD 2013, 62).



$\ln y_{i0}$  denotes the natural logarithm of GDP per capita for each country in the year 1994, and as this variable is constant over time, it will be included in the category  $Z_i$ . The coefficient of this variable represents the rate of convergence. Due to the conditional convergence effect,  $\ln y_{i0}$  is expected to have a negative relationship with growth.

$Changek_{it}$  represents the annual change in physical capital.  $TLF_{it}$  is the total labor force growth rate.  $y_{i0}$ ,  $Changek_{it}$  and  $TLF_{it}$  are called the conditioning variables.

$H_{t-1}$  is the level of human capital in the previous year. The human-skill index is used as a proxy of human capital.  $ChangeH$  denotes the change in human capital from year  $t - 1$  to year  $t$ .

Productive expenditure (*exp*); distortionary taxation (*tax*) and fiscal balance (*Balance*) are used to capture the effect of fiscal policy on economic growth rate.

From the existing literature especially macroeconomic theory, the following variables constitute macro control variables:

$INF_{it}$  is the inflation rate which proxies macroeconomic stability and is expected to be negatively related to economic growth rate.

$OPENG_{it}$  denotes trade openness of goods<sup>22</sup>, which measures the extent to which a country is integrated with the rest of the world. In general, trade liberalization promotes economic performance and it is expected to have a positive correlation with the economic growth rate.

All the explanatory variables mentioned above (except  $\ln y_{i0}$ ) change with different countries and over time, thereby they will be included in the category  $W_{it}$  and their averages in the category  $\bar{W}$ , in the equation (2.2).

To test whether the effect of energy taxes on growth rate depends on the levels of polluting energy use, a country's richness, and commercial openness of goods; we estimate a second regression equation with a similar specification to model (2.2) but one that additionally includes interaction terms between energy taxes and each of the total final consumption of polluting energy products as a share of total energy use, natural logarithm of initial value of

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<sup>22</sup> Since energy taxes are expected to affect the production of goods more than services and as we later aim to explore whether growth impacts of energy taxes depend on the level of trade openness of goods and services has been excluded from trade openness index.

GDP per capita, and trade openness of goods respectively. This second model is described by equation (2.3) below.

$$gr_{it} = \Psi + \beta_1 ET_{it} + \beta_2 (ET_{it} \times TFCPEP_{sh_{it}}) + \beta_3 (ET_{it} \times lny0_{it}) + \beta_4 (ET_{it} \times OPENG_{it}) + \theta Z_i + \delta W_{it} + \gamma \bar{W}_i + a_i + \phi \lambda_t + \varepsilon_{it} \quad (2.3)$$

The estimated marginal effect of energy taxes in this model is equal to:

$$\frac{\partial gr}{\partial ET} = \hat{\beta}_1 + \hat{\beta}_2 \cdot TFCPEP_{sh_{it}} + \hat{\beta}_3 \cdot lny0_{it} + \hat{\beta}_4 \cdot OPENG_{it} \quad (2.4)$$

## 2.4. Data

This study is based on panel data sets covering 31 OECD countries over the period 1994-2013 to examine the nature of relationship between energy based taxes and economic growth. We use annual data obtained from five main sources: (a) World Development Indicators (WDI) published by the World Bank; (b) the Organization for Economic Co-operation and Development (OECD); (c) Government Finance Statistics (GFS) published by the International Monetary Fund (IMF); and (d) International Energy Agency (IEA). Data on human capital stock are performed by the “Laboratoire d’Économie Appliquée au Développement (LEAD)” in Toulon University (France). Summary and data source for each variable is listed in Appendix (2.A).

- *Energy taxes proxy*

As we mentioned earlier, in this chapter we propose a new approach to measure energy taxes. This approach takes into account not only the revenue generated but also the variation in the tax base. In line with (OECD 2006) the energy taxes are levied on petrol and diesel for transport purposes and on fossil fuels and electricity for stationary purposes. Therefore, to account for the variation in the use of energy products that are harmful to the environment, the total final consumption of energy products that pollute the environment through carbon emissions is considered as a proxy of energy taxes’ base. The energy products include: coal and coal products, oil products, natural gas and electricity. Electricity is different from other energy products as it is a secondary energy generated through a primary energy, which can be polluting (e.g. coal, oil, natural gas) or clean (e.g. hydro, nuclear, solar, tides, wind...etc). To ensure that only the electricity generated by a polluting fuel was included, the total final consumption of electricity was multiplied by the rate of total final consumption of electricity

generated from oil, gas and coal sources (% of total electricity generated) for a given year. Thus, the electricity category used in the energy taxes' base shows the energy content or pollutant emissions, of underlying primary fuel used to generate electricity, rather than electricity itself. We call it "polluting electricity". We then computed the energy tax revenue per unit of total final consumption of polluting energy products, expressed in USD per ton of oil equivalent. It was considered as a proxy of energy taxes. The elements of this proxy are presented in appendix (2.A).

- *Interaction terms*

As previously mentioned, the purposes of this chapter are to examine the nature of the relationship between energy taxes and economic growth rate, and to explore whether this relationship depends on the level of other variables in the economy. As energy is an essential input of the production process, especially in the industrial sector, and as energy taxes are oriented toward polluting energy, we expect that economies that are more heavily dependent on polluting energy for production than clean energy, to be more sensitive to energy taxes. To control this effect, the proxy of energy taxes is interacted with the proxy of the dependency of production on energy use targeted by energy taxes. The later proxy is measured by the total final consumption share of coal and coal products, oil products, natural gas and polluting electricity in the total final consumption of energy. Coal and coal products, oil products, natural gas and polluting electricity are considered as polluting energy products. According to Ito (2017), the consumption of polluting energy products is expected to have a negative linkage to economic growth.

The effect of energy taxes on growth may depend also on the initial level of a country's richness measured by the initial level of GDP per capita. The justification of this hypothesis is mentioned in the section 1.1 of the first chapter. We tested this assumption in the first chapter when we used the total revenues of environmentally related taxes measured in percent of GDP as a proxy of environmental tax. In this chapter we want to verify the validity of this assumption by using a new proxy of energy taxes. To this end, the proxy of energy taxes has been interacted with the natural logarithm of initial value of the GDP per capita in each country in the year 1994.

Due to an increased energy taxes, the relative prices of final consumption goods and production inputs increase with the increasing of prices of electricity, fuel, and in fact all

inputs whose price strongly depends on transportation costs (see also [Fullerton and Heutel, 2007](#); [Martinez et al., 2012](#)). This will increase the costs of produced goods. Therefore, firms reduce their domestic market production at previous prices, or they offer the same quantity at higher prices. In both cases, the consumption of goods will decrease, causing a decline in growth rate. In the era of globalization, international markets have become a substitute for domestic markets, especially for small countries. Hence, if companies were able to transfer that additional environmental cost to foreign markets, or offset the decline in the quantity produced to local markets through exportation to new markets, that may pay more attention to environmental protection topics ([OECD, 2010b](#)), we expect that pollution taxes will not be harmful to growth rate. Conversely, if these assumptions were not to be carried out, these taxes might have a negative impact on growth through increasing input prices, rising prices for the consumer and decreasing competitiveness of products in international markets. Consequently, we suppose that the economic growth impacts of energy taxes may depend on the degree of a country's trade openness toward goods. In order to test this proposition, an interaction term between energy taxes and the index of openness to international goods' trade has been used in this study. The calculations of the variables TFCPEP, lny0 and OPENG are presented in appendix (2.A).

After identifying the variables and collecting their data, we used a multiple imputation procedure to treat missing data. Appendices (1.B, 1.C) provide the details about this procedure. Table (1.1) in the first chapter shows the descriptive statistics of the variables before and after multiple imputation process.

To check the robustness of the model used in this chapter, firstly, using the QIC program, we verified whether certain or all the four categories of control explanatory variables should be included in the CRE model. Appendix (2.B) shows this program. Secondly, in appendix (2.C), we employed the Variance Inflation Factor (VIF) test to verify the absence of multicollinearity. Finally, in appendix (2.D), panel unit root tests were used to demonstrate whether the time series of energy taxes (ET) are stationary. We found that all the four categories of control explanatory variables should be included in the CRE model, that there is absence of multicollinearity, and that the time series of energy taxes are stationary.

## 2.5. Results and Discussion

### 2.5.1. In the short term

Following the *Variable Addition Test (VAT)* for each of the equations (2.2 and 2.3) before and after multiple imputation, (please see appendix (2.E) for the details of tests), we reject the null hypothesis, ( $\gamma \neq 0$ ). Consequently, all the models have correlated random effects estimates. The results from estimating Eq. (2.2 and 2.3), before and after multiple imputations, are presented in column (1) and (2) respectively in table (2.1). Firstly, we focus our discussion on the estimations results that we have obtained from the regressions after implementing multiple imputations process, then we compare these results with those obtained from the regressions estimations before the multiple imputations process.

The results in column (1), after MI, indicate that energy taxes are negatively associated with economic growth rate in the short term. A 1 US \$ increase per ton of oil equivalent of fossil fuel energy use is associated with a 0.7 percent decrease in growth rate over the year. Moreover, when energy taxes interact with TFCPEP\_sh, lnY0 and OPENG in column (2), After MI, the coefficient of energy taxes increases from 0.007 to 0.049. This means that the magnitude of the correlation between economic growth rate and energy taxes is sensitive to the interaction of energy taxes with other variables in the economy.

The results of the model with the interaction terms, reported in column (2), After MI, also show that an increase in energy taxes leads to lower economic growth as the share of total final consumption of polluting energy products in the energy mix increases. This result suggests that the use of energy taxes in economies, which depend more heavily on polluting energy for production processes than cleaner energies, harms the economic growth rate. We can conclude from this result that the switch to clean energies could have a positive impact on growth rate in countries that receive high revenue from energy taxes per ton of oil equivalent. The trend towards clean energy production and investing in new technology to increase the efficiency of polluting energy use may help reduce the proportion of polluting energy consumption in the overall energy mix of the economy and thus reduce the negative impact of energy taxes on economic growth. We also find that the interaction of energy taxes with the natural logarithm of initial GDP per capita was positive and significant, indicating that an increase in energy taxes leads to an increase in the economic growth rate as the initial level of a country's richness rises. This result allows us to say that the more a country is rich, the more

	Before MI		After MI	
	(1)	(2)	(1)	(2)
ET	<b>-0.005*</b> (0.003)	<b>-0.046***</b> (0.017)	<b>-0.007**</b> (0.003)	<b>-0.049***</b> (0.018)
TFCPEP_sh		0.055 (0.072)		0.063 (0.067)
ET # TFCPEP_sh		-0.00004 (0.00004)		<b>-0.0001*</b> (0.00006)
lnY0	-0.017 (0.214)	<b>-1.053***</b> (0.386)	-0.071 (0.204)	<b>-1.175***</b> (0.422)
ET # lnY0		<b>0.004***</b> (0.001)		<b>0.005***</b> (0.0017)
OPENG	<b>0.034**</b> (0.016)	<b>0.049**</b> (0.018)	<b>0.027*</b> (0.016)	<b>0.041**</b> (0.019)
ET # OPENG		-0.00006 (0.00004)		-0.00004 (0.00005)
Change k	0.204 (0.158)	0.183 (0.153)	<b>0.213*</b> (0.127)	0.191 (0.120)
TLF	24.434 (9.852)	21.766 (9.912)	9.202 (9.625)	9.622 (9.718)
Ht-1	<b>19.001***</b> (6.152)	<b>16.969***</b> (6.607)	8.602 (6.284)	7.341 (5.915)
ChangeH	<b>25.020**</b> (10.299)	<b>21.036**</b> (9.550)	<b>26.003***</b> (9.906)	<b>22.431**</b> (8.923)
exp	<b>-0.185**</b> (0.087)	<b>-0.180**</b> (0.083)	<b>-0.278***</b> (0.103)	<b>-0.278**</b> (0.108)
tax	-0.169 (0.106)	-0.166 (0.087)	-0.123 (0.099)	-0.121 (0.100)
Balance	0.076 (0.055)	<b>0.092*</b> (0.049)	<b>0.095**</b> (0.045)	<b>0.093**</b> (0.047)
INF	-0.014 (0.063)	-0.041 (0.063)	<b>-0.038***</b> (0.013)	<b>-0.035**</b> (0.018)
Observations	509	509	589	589
Number of countries	31	31	31	31
Number of imputations			100	100
Largest FMI			0.43	0.28

Note: \*, \*\*, and \*\*\* indicates the significance level at 10, 5, and 1% respectively based on the two-tailed test.

Standard error estimates are in parentheses. The dummy variables of time ( $\lambda_t$ ), the averages of the variables that change across the time ( $\bar{W}_i$ ) and the constant were included in the regressions but they are not presented in this table.

*Table 2.1: Regressions with energy tax revenue per polluting energy products (US \$ / ton of oil equivalent)*

*Dependent variable: Annual percentage growth rate of GDP per capita*

its ability to impose energy taxes and to bear its burdens increases. The last term of interaction between energy taxes and trade openness of goods appears to be slightly negatively associated with growth rate but without statistical significance. The control variables are consistent with

the findings of previous empirical studies. In order to know which equation we should use to interpret the findings of control variables, we ran QIC program for equations 2.2 and 2.3. As mentioned in appendix (2.D), the best fitting model is the one that has the smallest value of the average of *QIC*. Table (2.2) reports the descriptive statistics of *QIC* values.

Variable	Obs	Mean	Std. Dev.	Min	Max
<b>QICeq2.2</b>	100	228734.4	405.2977	228212	230428.2
<b>QICeq2.3</b>	100	216639.6	437.7918	216014.7	218438.6

Source: Author

Table 2.2: The descriptive statistics of the values of *QIC* for equation (2.2) and (2.3)

The best equation to interpret the results is equation 2.3 which has the least value of the mean of *QIC* (216639.6). Thereby, column (2), After MI, in table (2.1) is used to explain the effects of selected control variables on growth rate. Consistent with the neoclassical hypothesis of convergence, a higher level of initial GDP per capita is associated with a lower economic growth rate. The estimated coefficient of  $\ln Y_0$  is strongly significant. In line with much of the literature, openness to international trade of goods is positively correlated with economic growth rate and statistically significant. Total labor force growth rate was found to have positive effect on growth rate but were statistically non-significant. The annual change in human capital is positively and significantly associated with economic growth rate. Concerning financial policy variables, productive expenditure is appeared to be negatively correlated with economic growth rate. This result consistent with some empirical studies that found that government spending can undermine economic performance due to inefficient use of money (Alesina et al., 2002) and/ or due to “resource displacement” (Ramey, 2011). The distortionary taxation doesn’t have a significant correlation with economic growth, while the fiscal balance is positively associated with it. Finally, inflation rate is negatively related to economic growth rate.

Now we return to compare our results before and after implementing the multiple imputation process. This will help us to understand the information and features that we have obtained through the use of this missing data treatment. In order to accomplish this objective, we estimated the same models as before using an unbalanced database (data with missing observations). The estimations of equations 2.2 and 2.3 are presented in table (2.1), (before

*MI*), column (1) and (2) respectively<sup>23</sup>. After comparing the results obtained before and after IM, we observed that the relationship between energy taxes and economic growth rate becomes more significant by using imputed database in regression 2.2. We also found that the interaction term between energy taxes and the share of total final consumption of polluting energy products in the energy mix, presented in equation 2.3, loses its significance when we use the incomplete database. This difference in results shows that the multiple imputation improved data quality and contributed to obtaining reliable estimates.

The energy tax revenue per unit of its tax base was employed as a proxy of energy taxes in this chapter. To compare the results obtained by this approach with those obtained by using OECD measurements, we estimated equation 2.3 using four units of energy taxes: percent of GDP (ET\_GDP), a share of total tax revenues (ET\_TTR), per capita (ET\_PC), and millions of USD (ET\_MUSD). For the last unit (ET\_MUSD), we took the logarithm in order to simplify the coefficient's interpretation. These units are provided by OECD Statistics. The estimations are based on unbalanced database (before imputation). The results are reported in the appendix (2.3). In order to simplify the comparison, estimation results of equation 2.2 by using energy tax revenue per unit of its tax base (ET) are reported in column (1). The results presented in the columns (2-5) do not show any significant association between energy taxes and economic growth rate, whereas this association is significant in column (1). This shows that taking into account the variation in the tax base of energy taxes is important to capture a significant correlation between energy taxes and economic growth rate.

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<sup>23</sup> The results of The Variable Addition Test (VAT) of equations 4 and 5, which have been implemented with unbalanced dataset, are reported in the appendix (2.G). Following the results of this test we reject the null hypothesis, therefore  $\gamma \neq 0$  and the models have correlated random effects estimates



	(1)	(2)	(3)	(4)	(5)
	<b>ET</b>	<b>ET_GDP</b>	<b>ET_TTR</b>	<b>ET_PC</b>	<b>ET_MUSD</b>
Energy taxes proxy	<b>-0.005*</b>	-0.623	-0.226	-0.001	-1.059
	(0.003)	(0.654)	(0.221)	(0.001)	(0.690)
lnY0	-0.017	0.005	0.008	-0.011	-0.033
	(0.214)	(0.191)	(0.190)	(0.185)	(0.187)
Change k	0.204	0.208	0.208	0.210	0.206
	(0.158)	(0.156)	(0.157)	(0.158)	(0.154)
TLF	<b>24.434**</b>	<b>24.217**</b>	<b>23.721**</b>	<b>24.841**</b>	<b>25.714**</b>
	(9.852)	(9.951)	(10.0132)	(9.987)	(10.139)
Ht-1	<b>19.001***</b>	<b>17.345***</b>	<b>17.805***</b>	<b>17.344***</b>	<b>16.207**</b>
	(6.152)	(6.263)	(6.242)	(6.381)	(6.581)
ChangeH	<b>25.020**</b>	<b>24.517**</b>	<b>24.727**</b>	<b>23.848**</b>	<b>22.348**</b>
	(10.299)	(10.113)	(10.174)	(10.134)	(10.784)
exp	<b>-0.185**</b>	<b>-0.189**</b>	<b>-0.192**</b>	<b>-0.175**</b>	<b>-0.163**</b>
	(0.087)	(0.088)	(0.087)	(0.082)	(0.078)
tax	-0.169	-0.112	-0.145	-0.125	-0.154
	(0.106)	(0.101)	(0.111)	(0.099)	(0.106)
Balance	0.076	0.059	0.056	0.059	0.072
	(0.055)	(0.055)	(0.056)	(0.057)	(0.055)
INF	-0.014	-0.011	-0.012	-0.004	-0.055
	(0.063)	(0.059)	(0.058)	(0.066)	(0.052)
OPENG	<b>0.034**</b>	<b>0.042**</b>	<b>0.042**</b>	<b>0.042**</b>	<b>0.040**</b>
	(0.016)	(0.017)	(0.017)	(0.018)	(0.017)
Observations	509	509	509	509	509
Number of countries	31	31	31	31	31

Note: \*, \*\*, and \*\*\* indicates the significance level at 10, 5, and 1% respectively based on the two-tailed test. Standard error estimates are in parentheses. The dummy variables of time ( $\lambda_t$ ), the averages of the variables that change across the time ( $\bar{W}_i$ ), and the constant were included in the regressions but they are not presented in this table.

*Table 2.3: Regression of equation 2.2 using the four measurements provided by OECD statistics of energy taxes*

### 2.5.2. In the long term

In order to capture the impact of energy taxes on economic growth rate in the long term, we re-estimate the equations 2.2 and 2.3 with lagged values of all explanatory variables for five periods, each period being one year. The results are presented in table (2.4). Column (1) and (2) for every lag represent estimates results of equation 2.2 and 2.3 respectively. Column (1) of every lag shows that the correlation between energy taxes (ET) and the economic growth rate (gr) is statistically insignificant. This correlation becomes negative and statistically significant when energy based taxes interact with other variables in the first two lagged periods. This means, in the long term, that the negative association between economic growth rate and energy taxes could come from the interaction of energy taxes with other variables in the economy, especially with the total final consumption of polluting energy products as a share in energy mix and the country's openness of trade goods. The interaction between ET

and TFCPEP\_sh appeared to be negatively related to economic growth rate when the years of lags equal to one, two, and four. We also find that the interaction term between ET and OPENG has a negative effect on economic growth rate in all lagged periods but with statistical significance only when the number of lagged years equals to five. This shows that, the higher the level of country's commercial openness of goods, the more the increase of energy taxes harms economic growth rate in the long term. This could be explained by increasing input costs because of energy taxes, which raises prices for the consumer and decreases competitiveness of products in international markets. Thus the exportation decreases leading to economic growth decline. Conversely, the results reveal that the interaction between the proxy of energy taxes and the natural logarithm of initial GDP per capita was positive in the five lags. This indicates that, in the long term, an increase in energy taxes could lead to an increase in the economic growth rate as the initial level of a country's richness rises. This result could be interpreted by two factors. Firstly, the nature of the economic growth motor in rich countries, which usually depends on human capital accumulation rather than physical capital accumulation. Therefore, energy taxes oriented toward polluting energy products, which are used in physical capital accumulation, will not harm economic growth for rich countries as much as poor countries. Secondly, the efficiency and improvement in energy use usually require investments in high technology, R&D, and renewable energy. As rich countries have a greater ability to realize these investments than poor ones, they could reduce the negative impact of energy based taxes on growth more easily than poor countries.

	Lags=1		Lags=2		Lags=3		Lags=4		Lags=5	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
ET	-0.004 (0.003)	<b>-0.034*</b> (0.020)	-0.001 (0.002)	<b>-0.041**</b> (0.018)	0.002 (0.004)	-0.030 (0.020)	0.001 (0.003)	-0.024 (0.019)	0.004 (0.004)	-0.020 (0.019)
TFCPEP_sh		-0.066 (0.086)		-0.042 (0.086)		-0.062 (0.089)		<b>-0.139*</b> (0.087)		-0.038 (0.082)
ET # TFCPEP_sh		<b>-0.0001*</b> (0.00004)		<b>-0.0001*</b> (0.00004)		-0.00004 (0.00004)		<b>-0.0001**</b> (0.00005)		-0.0001 (0.00005)
lnY0	-0.013 (0.176)	<b>-0.903**</b> (0.451)	-0.007 (0.177)	<b>-1.048**</b> (0.404)	0.070 (0.170)	<b>-0.810*</b> (0.430)	0.188 (0.173)	-0.534 (0.404)	0.134 (0.160)	-0.615 (0.412)
ET # lnY0		<b>0.003**</b> (0.001)		<b>0.004**</b> (0.001)		<b>0.003**</b> (0.001)		<b>0.00374***</b> (0.001)		<b>0.003**</b> (0.001)
OPENG	<b>0.026*</b> (0.016)	<b>0.040*</b> (0.024)	0.011 (0.021)	0.021 (0.027)	0.013 (0.021)	0.024 (0.026)	0.014 (0.019)	0.026 (0.020)	0.0030 (0.0170)	<b>0.046**</b> (0.019)
ET # OPENG		-0.0001 (0.00006)		-0.00005 (0.00006)		-0.0001 (0.00006)		-0.0001 (0.00006)		<b>-0.0001**</b> (0.0001)
Change k	<b>0.272***</b> (0.065)	<b>0.278***</b> (0.068)	0.031 (0.092)	0.029 (0.096)	0.085 (0.077)	0.080 (0.090)	-0.002 (0.089)	0.014 (0.077)	0.047 (0.123)	0.059 (0.106)
TLF	3.479 (11.657)	6.730 (11.608)	<b>-19.059**</b> (8.390)	<b>-15.052*</b> (8.046)	<b>-28.071***</b> (8.064)	<b>-24.253***</b> (8.143)	-7.729 (11.334)	-2.947 (12.113)	-17.533 (14.194)	-14.001 (13.926)
Ht-1	0.214 (8.783)	-5.337 (8.790)	0.863 (9.693)	-2.946 (8.976)	1.335 (10.724)	-2.308 (9.783)	-2.2394 (12.520)	-7.889 (12.112)	-6.963 (15.248)	-10.108 (14.524)
ChangeH	<b>21.856***</b> (8.376)	<b>14.539*</b> (8.179)	-4.811 (16.052)	-11.140 (15.665)	16.627 (12.128)	10.077 (11.093)	-16.823 (20.106)	-25.999 (18.326)	14.340 (9.601)	7.860 (10.258)
exp	-0.120 (0.080)	-0.079 (0.078)	-0.0707 (0.111)	-0.029 (0.108)	-0.080 (0.138)	-0.046 (0.132)	-0.154 (0.125)	-0.100 (0.121)	<b>-0.175*</b> (0.100)	<b>-0.148*</b> (0.091)
tax	0.003 (0.089)	-0.018 (0.087)	0.026 (0.104)	0.009 (0.105)	0.060 (0.110)	0.029 (0.110)	0.068 (0.105)	0.019 (0.117)	0.069 (0.101)	0.001 (0.103)
Balance	0.040 (0.040)	0.049 (0.045)	0.060 (0.042)	0.068 (0.048)	-0.033 (0.044)	-0.027 (0.044)	-0.091 (0.060)	-0.086 (0.061)	<b>-0.142**</b> (0.065)	<b>-0.145**</b> (0.067)
INF	<b>-0.050***</b> (0.009)	<b>-0.064***</b> (0.017)	<b>-0.054***</b> (0.008)	<b>-0.063***</b> (0.015)	<b>-0.064***</b> (0.011)	<b>-0.074***</b> (0.021)	<b>-0.061***</b> (0.014)	<b>-0.084***</b> (0.017)	-0.014 (0.021)	-0.017 (0.025)
Observations	554	554	520	520	485	485	449	449	411	402
Number of countries	31	31	31	31	31	31	31	31	31	31
Number of imputations	100	100	100	100	100	100	100	100	100	100
<b>Largest FMI</b>	<b>0.24</b>	<b>0.15</b>	<b>0.23</b>	<b>0.08</b>	<b>0.12</b>	<b>0.12</b>	<b>0.16</b>	<b>0.10</b>	<b>0.15</b>	<b>0.17</b>

Note: \*, \*\*, and \*\*\* indicates the significance level at 10, 5, and 1% respectively based on the two-tailed test. Standard error estimates are in parentheses. The dummy variables of time ( $\lambda_t$ ), the averages of the variables that change across the time ( $\bar{W}_t$ ), and the constant were included in the regressions but they are not presented in this table.

Table 2.4: Estimates of equations 2.2 and 2.3 with lagged values for all explanatory variables

### 2.5.3. Marginal effect of energy taxes

To estimate the marginal effect of energy taxes on economic growth rate per capita, “*mimrgns, dydx()*” Stata command was used. It calculates the average marginal effects of explanatory variable on dependent variable. The estimations are reported in table (2.5). The results show that the average marginal effect of energy taxes on economic growth rate is negative in the short term. However, the magnitude of this effect decreases in the long term and the sign becomes positive when the number of lagged years equal to three and five.

	Short term	Long term				
		Lag1	Lag2	Lag3	lag4	Lag5
<i>dgr/ET</i>	-0.011***	-0.007***	-0.005**	0.0001	-0.003	0.001

Note: \*, \*\*, and \*\*\* indicates the significance level at 10, 5, and 1% respectively.

*Table 2.5: Average marginal effect of energy taxes on economic growth rate per capita*

## 2.6. Conclusion

In this chapter we have provided empirical evidence of the macroeconomic relationship between energy based taxes and economic growth rate in the short and long term. We have focused our analysis on this category of environmentally related taxes for two reasons: Firstly, energy taxes constitute the largest proportion in terms of the number of taxes imposed and the revenues achieved. Secondly, to be able to take into account for not only the revenue generated from taxes but also the variations in the tax base. The multiple imputation method with an Expectation Maximization Bootstrapped algorithm was implemented in order to complete an un-balanced data set of 31 OECD countries over 20 years, improving data quality and inferences validity. The Correlated Random Effects (CRE) panel data model developed by [Wooldridge \(2010\)](#) was used to estimate the effects. Empirical results reveal that when we neglect the interaction between energy taxes and other variables in the economy, the relationship between energy taxes and economic growth rate was found to be negative and significant only in the short term. When this interaction was taken into account, energy taxes negatively associated with economic growth rate, in the short and long term (two lagged years). This shows that the negative effect of energy based taxes on economic growth rate, on the long term, occurs through the interaction of energy taxes with other variables in the economy. In particular, we found that energy taxes seem to have a negative correlation with economic growth rate in the short and long term and this correlation relies significantly on the level of economic dependence on polluting energy use as a share of the mix energy in the short and long run, and on commercial openness of goods only in the long run (the fifth lagged years). On the other hand, our study shows that an increase in energy taxes can significantly enhance economic growth, as the initial level of a country's richness increases. Finally, we compared the estimation results obtained by using our proposed approach to measure energy taxes with those provided by the OECD statistics in the short term. We found that taking into account the variation in the tax base is important to capture a significant correlation between energy taxes and economic growth rate. We believe that our results could

be insightful to policymakers, especially after COP21 (the agreement signed in Paris in 2015 concerning climate changes). Governments having introduced energy taxes or planning to increase these taxes in order to curb emissions, should at the same time work to encourage the shift toward clean energy use and to increase the efficacy of polluting energy use, because this could reduce the negative effect of energy taxes on economic growth. Additionally, the government should provide support to industrial enterprises that direct their production for export, in order to compensate for part of the increase in costs resulting from energy taxes. This may improve their competitiveness in the global markets and thus increase their exports. On the other side, rich countries are more able to use environmentally related taxes as an instrument for environmental policies, without harming economic growth, than poor countries. Finally, the method used to measure energy taxes is an important issue and it can change the implications of public policy. For this reason, we propose to build a new measure of the categories of environmentally related taxes which takes into account the variation in their bases.

### 3. Chapter 3: Physical capital, human capital, CO2 emissions, eco-innovation, public debt, energy taxes and economic growth in OECD countries

#### Abstract

This chapter is an extension of the second chapter. It explores the channels through which energy taxes may affect economic growth, using a simultaneous equations model for a balanced panel data of 31 OECD countries over the 1994–2013 period. The empirical results reveal a negative impact of energy taxes on physical investment in the short and long term. This impact is negatively sensitive to the existence and level of public debt. Additionally, the results show that energy taxes have an indirect effect on human capital through their impact on CO2 emissions. The taxes on energy products are able to reduce both the *flux* and the *stock* of CO2 emissions that have a negative impact on human capital skill in the short and long term. Finally, we found that energy taxes can encourage eco-innovation in the short and long term. However, eco-innovation only promotes economic growth only after a period of two or three years.

#### 3.1. Introduction

According to the theoretical literature on environmental economics, imposing taxation on pollution (e.g., energy taxes) can affect economic growth through three main channels: physical capital (physical investment); human capital; and eco-innovation. On one hand, these taxes harm economic growth through their negative impact on physical capital (see for instance, [Bovenberg and Heijdra, 1998](#); [Labandeira et al., 2004](#); [Ono 2003b](#); [Siriwardana et al., 2011](#); and [Wang et al., 2015](#)). On the other hand, when the level of pollutant emissions decreases, as a result of energy taxes, this will improve public health and promotes learning capacity, reinforcing human capital accumulation and thus economic growth ([Aloi and Tournemaine, 2011](#); [Chen et al., 2017](#); [Ewijk and Wijnbergen, 1994](#); [Gehrsitz, 2017](#); [Gradus and Smulders, 1993](#); [Kim et al., 2017](#); [Mabahwi et al., 2014](#); [Pautrel, 2012](#); and [Vellinga, 1999b](#)). Moreover, some studies show that energy taxes encourage investment in

environmental technologies and therefore stimulate economic growth (Acemoglu et al., 2012 ; Ambec et al., 2013; Hart, 2008; Hattori 2017; Nakada, 2004; OECD, 2010a; and Porter and van der Linde, 1995). Figure 3.1 shows these channels.

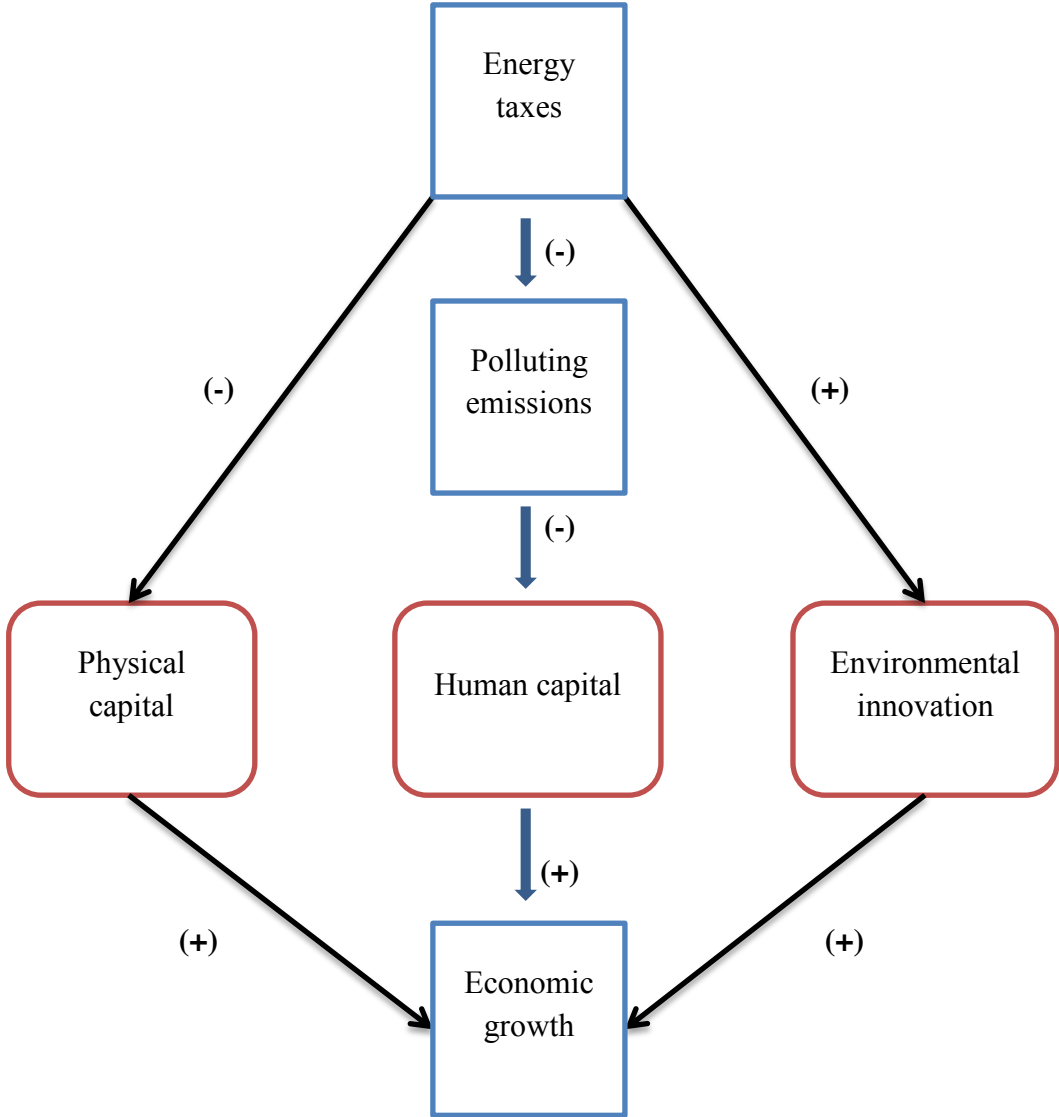


Figure 3.1: The channels through which energy taxes can affect economic growth

The impact of energy tax on economic growth has been widely discussed. Nonetheless, the majority of studies are theoretical, and empirical research examining the validity of these hypotheses is rather weak. This is probably due to the lack of available data on energy taxes.

In addition, we noticed that the majority of the theoretical models applied to studying the effect of energy taxes on economic growth assume that the government finances its

expenditures only through taxes and that the public budget is balanced in every period. As a result, these models ignore any burden associated with government debt. Many studies showed that, high levels of public debt can lead fiscal policy to adversely affect economic growth, while low levels of public debt allow fiscal policy to promote economic progress (Baharumshah et al, 2017; Bhattarai et al., 2014; Chen et al. 2016; Gogas et al., 2014; Galstyan and Velic, 2017; Gwartney et al. 1998; Teles and Cesar Mussolini 2014a). In recent years, sustaining a high level of public debt-to-gross domestic product (GDP) ratio has been one of feature of advanced economies. Since the global financial crisis in 2008, many OECD countries, such as Italy, Spain and Greece, have found themselves with high debt-to-GDP ratios. These ratios are due to high budget deficits from rising public spending and declining tax revenue with the aim of saving the banking sector and stabilizing economic growth.

In view of the above, the econometric approach in this chapter aims to achieve two objectives. Firstly, to investigate the potential impact of energy taxes on physical capital (physical investment), human capital and environmental innovation in the context of an endogenous growth model, where physical capital, human capital and environmental innovation are the three mains channels through which energy taxes could affect economic growth. Secondly, to explore whether this impact is sensitive to the existence and level of public debt. In other words, does ignoring public debt alter the impact of energy taxes on these channels and thus on growth? The analysis covers the short and long term for both objectives.

This chapter innovates in three ways: Firstly, to our knowledge, this is the first attempt at empirically testing the validity of these hypotheses together for the short and long-term using a simultaneous equations model (SEM). Secondly, we provide the first ever macro-econometric evidence on how sensitive of the effects of energy taxes on physical investment, and thus on economic growth are with regard to the existence and the level of public debt. Finally, the analysis is based on a balanced dataset for a large sample of OECD countries and uses multiple imputation method for completing the missing data.

After a review of the existing relative literature in section 3.2, the rest of this article is organized as follows. Section 3.3 presents the empirical model. Section 3.4 contains a description of the data. Section 3.5 shows how the endogeneity problem is treated. Section 3.6 highlights the estimator used to estimate the coefficients for equations. In section 3.7, we discuss the empirical results for the short and long term. The final section concludes the article by commenting on the main results.



## **3.2. Literature review**

Many existing studies on the effect of energy taxes on economic growth through its impact on physical capital (physical investment), human capital, and eco-innovation are performed on a piecemeal basis and without a comprehensive model in mind, thus ignoring the potential interaction between these variables. Therefore, this chapter reviews the literature under five subsections, i.e., (a) endogenous growth factors, (b) energy taxes and investment, (c) energy taxes and CO<sub>2</sub> emissions, (d) CO<sub>2</sub> emissions and human capital, and (e) energy taxes and environmental innovation.

### **3.2.1. Endogenous growth factors**

According to the endogenous growth theory, there are four main engines of economic growth rate on the long term: physical capital (Romer, 1986), human capital (Lucas Jr., 1988), innovation (Romer, 1990) and public capital (Barro, 1990). The literature review of the environmental economic shows that energy taxes can influence economic growth through three channels: physical capital, human capital, and innovation. The effect mechanism of energy taxes on each of these channels is explained in the following sections.

### **3.2.2. Energy taxes and physical capital (physical investment)**

Several studies show that taxes imposed on energy products negatively affect economic growth due to a negative impact on physical capital (physical investment) through the following mechanism. In the short term, energy taxes lead to an increase in the relative prices of fossil fuels which are considered as a production factor. Price increases decrease the quantity of fossil fuel used in production processes, thus reducing the productivity of physical capital compared to the situation where there are no taxes (Labandeira et al., 2004). By modeling the quality of the environment as a durable consumption good in an overlapping generations model, Bovenberg and Heijdra (1998) confirm the result of Labandeira et al. (2004) but only over the long term. They found that environmental tax increases make future generations suffer from a smaller physical capital stock, but benefit from a larger stock of natural capital. Therefore, in the long term, economic growth decreases due to the lower physical capital that the younger generation will have. Ono (2003) showed that a higher environmental tax increases production costs for firms, leading to a decrease in the wages paid to workers and the taxes paid to the government. This negative income effect leads to decline in savings and investment, thereby lowering the economic growth rate. In a more recent study, Siriwardana et al. (2011) explored the effects of carbon tax on the Australian

economy by employing a computable general equilibrium (CGE) model. They found that the introduction of a \$23 tax on carbon dioxide emissions led to a decline in Australia's real GDP by about 0.68 per cent in the short term. They explained the GDP contraction through four factors: (a) an increase in consumer prices, (b) a reduction in energy consumption, (c) a decline in real household consumption, and (d) a reduction in export volumes. All of these factors directly and negatively affected physical investment. In the same context, using an overlapping generation model [Wang et al. \(2015\)](#) showed that pollution tax can reduce pollution but causes a distortion in the rate of return to capital, thus damaging growth.

It is worth noting that all these studies are theoretical. There are no empirical studies to verify their validity at a macroeconomic level. This chapter proposes to fill this in this gap.

### **3.2.3. Energy taxes and CO2 emissions**

The effect of energy taxes on human capital is generally considered through its impact on polluting emissions. Therefore, in this section, we review the papers that examine the effect of energy taxes on CO2 emissions, which we consider as a proxy of polluting emissions, and in the next section we show how polluting emissions affect human capital. Imposing taxation on energy products is considered to be one of the most efficient tools for reducing polluting emissions resulting from development activities. However, empirical studies examining the validity of this hypothesis show conflicting results. [Bruvoll and Larsen \(2004\)](#) evaluated the environmental effects of CO2 taxes in Norway over the 1990-1999 period. They combined a Divisia index decomposition method and an applied general equilibrium model. They found that despite the relatively high Norwegian carbon tax rates, the impact on greenhouse gas emissions was modest. The taxes contributed to a reduction in onshore emissions of only 1.5 percent and a decrease of only 2.3 percent in overall emissions. They considered that the reason for these results was the exemption of a broad range of fossil fuel intensive industries from carbon taxes for fear of reducing competitiveness. Similarly, [Lin and Li \(2011\)](#) showed that although a carbon tax introduced by the government of Finland had a significant and negative effect on per capita CO2 emissions growth, the effects of a carbon tax on carbon emissions in Denmark, Sweden and Netherlands were not significant. [Loganathan et al. \(2014\)](#) also found that the carbon tax in Malaysia did not have much impact on the reduction of carbon emissions. In contrast, [Kim et al. \(2011\)](#) estimated the effects of a gasoline tax on CO2 emission reductions within the transportation sector in Korea over the 1999–2009 period. They found that when the CO2 tax on gasoline was charged an additional 50,000 per ton of CO2, carbon dioxide emissions could be reduced by 916,124 tons of CO2, without the

possibility of using more fuel efficient vehicles. If more efficient emitting less CO<sub>2</sub> were available, the tax effect on CO<sub>2</sub> reduction could reach 1,090,325 tons of CO<sub>2</sub>. In a similar study, using monthly data over the 1989-2008 period [Davis and Kilian \(2011\)](#) found that a 10-cent increase in gasoline tax would decrease CO<sub>2</sub> emissions from the transportation sector by about 1.5% and total carbon emissions by about 0.5% in the United States. More recently, using an unbalanced annual panel of US airline industry from 1995 to 2013 ([Fukui and Miyoshi 2017](#)) suggested that a 4.3 cents increase in aviation fuel tax would reduce carbon dioxide emissions in the US by approximately 0.14–0.18 % in the short run. However, due to the supposed rebound effect the percentage of reduction in CO<sub>2</sub> emissions would decrease to about 0.008–0.01% in the long run.

These conflicting findings have opened an avenue of research for investigating whether imposing tax has significant impact on carbon emissions. In addition, the majority of previous studies on this topic have been conducted for a specific economy (specific country), and therefore, they cannot generalize their results. Using 31 OECD countries, our study has enabled us to obtain general results.

#### **3.2.4. CO<sub>2</sub> emissions and human capital**

In this section, we firstly reviewed the theoretical works that showed the effect of pollution emissions, in general, on human capital. We then highlighted the studies that explored, in particular, the effect of CO<sub>2</sub> on human capital. According to theoretical studies, pollution emissions can negatively affect human capital through two channels: public health and learning ability. Many studies have examined the link between pollution and public health (see [Chen et al., 2017](#); [Gehrsitz, 2017](#); [Kim et al., 2017](#); and [Mabahwi et al., 2014](#)). However, to the best of our knowledge, there is no empirical research investigating the impact of CO<sub>2</sub> emissions on learning ability by using panel data, and majority of existing studies on this topic are theoretical. For example, in order to study the effect of environmental care on long-term economic growth, [Gradus and Smulders \(1993\)](#) expanded on the endogenous growth model of [Lucas \(1988\)](#) by assuming that pollution reduces the learning ability of people. In this case, the increased willingness to clean up pollution could stimulate growth through increasing human skills over the long term. To study the influence of environmental care on the short-term economic growth rate, [Vellinga \(1999\)](#) also expanded on the model of Lucas (1988) by assuming that output leads to pollution, and that there is a stock of pollution. In addition, he supposed that the stock of pollution remains constant over the long-term. This

hypothesis made the utility function dependent on consumption only, and the long-term growth rate was independent of the preference for a clean environment. His analysis for the short term showed a negative relationship between the level of pollution and human capital. If there was a high level of pollution, people's desire for consumption and investment decreases and they spend more time and resources on pollution abatement activities than studying, leading to a lower level of human capital and thus a lower economic growth rate. Likewise, [Ewijk and Wijnbergen \(1994\)](#) expanded on the model of [Lucas \(1988\)](#) by linking the scale of production to pollution. They found that pollution has a negative impact on productivity both directly in productive activities and in the learning process. More recently, [Pautrel \(2012\)](#) has demonstrated that, when long-run growth is driven by human capital accumulation, the effects of pollution on life expectancy may explain by themselves the influence of environment on growth.

To explain the causal link between CO<sub>2</sub> and air pollution mortality, [Jacobson \(2008\)](#) used the nested global-urban 3-D model, GATOR-GCMOM. He found that fossil-fuel CO<sub>2</sub> increases increase U.S. surface ozone, particulate matter, and carcinogens, thereby increasing death, hospitalization, asthma, and cancer rates. In the same context, [Jacobson \(2010\)](#) showed that local CO<sub>2</sub> emissions can increase local ozone and particulate matter due to feedbacks to temperatures, atmospheric stability, water vapor, humidity, precipitation and winds. Therefore, their corresponding health effects can increase premature mortality by 50-100 and 300-1000/per year in California and the U.S., respectively.

On the other side, [Satish et al. \(2012\)](#) evaluate the effects of increased CO<sub>2</sub> concentrations on decision making. To do this, six groups of four participants have been exposed to CO<sub>2</sub> at 600, 1,000, and 2,500 ppm (parts per billion) in an office-like chamber, for 2.5 hours per case. The sessions for each group took place on a single day. During each exposure case, participants completed a computer-based test of decision-making performance. The results showed that increases in CO<sub>2</sub> concentrations were associated with significant reductions in decision-making performance. In a similar and more recent study, [Allen et al. \(2016\)](#) studied the association between the carbon dioxide and cognitive function scores. They used twenty-four participants that spent 6 full work days (9 a.m. – 5 p.m.) in an environmentally controlled office space. The participants were been exposed artificially to different carbon dioxide (CO<sub>2</sub>) levels. Then, the cognitive assessment was performed daily using the Strategic Management Simulation (SMS) software tool, which is a validated, computer-based test, designed to test

the effectiveness of management-level employees through assessments of higher-order decision making ( [Satish et al., 2004](#)). Their results reveal a negative correlation between CO<sub>2</sub> and cognitive function scores. In addition, they found declines in cognitive function scores when the level of CO<sub>2</sub> concentration was increased.

After these results, carbon dioxide emissions are considered today as polluting emissions and have a negative impact on human cognition and decision-making.

### **3.2.5. Energy taxes and environmental innovation**

The assumption that energy taxes can spur environmental innovation is inspired by the “Porter hypothesis”. [Porter and van der Linde \(1995\)](#) argued that well-designed environmental regulation (in particular, market-based instruments such as taxes or cap-and-trade emissions allowances) can lead to “innovation offsets” that not only improve environmental performance, but also partially—and sometimes more than fully—offset the additional cost of regulation, through increasing the competitiveness of firms. The Porter hypothesis is based on a broad definition of innovation and on the effect of innovation on competitiveness. In this chapter, we focused our analysis on a specific type of innovation: environmental innovation. We then aspired to explore whether this type of innovation could promote the economic growth rate. Consequently, our literature review focuses on the studies based on this type of innovation. According to the [OECD \(2010a\)](#), the tax put on pollution leads firms with resources to seek new cleaner solutions through investing in environmental innovation, and firms with less resources to bring in the latest technologies already developed elsewhere. To study the response of different types of technologies to environmental policies, [Acemoglu et al. \(2012\)](#) employed a simple two-sector (clean and dirty inputs) model of directed technical change. They found that when the clean and dirty inputs (non-fossil and fossil fuels) were highly substitutable, the absence of governmental intervention, led to environmental degradation, because the initial productivity advantage of dirty inputs and the market size effect would direct innovation and production towards the dirty sector. However, the instruments used by environmental policy (carbon taxes, which change the relative prices of fossil fuel, and research subsidies) would be sufficient to *redirect* technical change to clean technologies and avoid an environmental disaster. Likewise, [Hattori \(2017\)](#) determined the conditions under which emissions taxes could spur eco-innovation. He used a model of endogenous and monopolistic environmental innovations, with perfect or imperfect competition in a polluting goods market. He showed that introducing higher emissions taxes

encourages innovation and diffusion of environmentally clean technologies if the price-elasticity of the demand for polluting goods are small and/or the tax burden on polluting firms is small. The empirical work of [Haščič et al. \(2010\)](#), which was based on a broad cross-section of countries over the 2000-2007 period, confirms the assumption of [Hattori \(2017\)](#). They found that environmental policy stringency plays a significant role in developing innovative means of air and water pollution abatement as well as solid waste management. The role of policy stringency comes from changing in the relative prices of production factors, driving firms to invent new methods of production to reduce the consumption of factors which had become relatively expensive. A microeconomic analysis performed by [Veugelers \(2012\)](#) using a Flemish CIS eco-innovation survey also confirms that government intervention can affect private sector innovations. Here, regulations and taxes are the most effective environmental policy instruments in inciting private firms to adopt clean technologies. However, using a panel data set of 22 Spanish manufacturing sectors for the 2008–2013 period, [Costa-Campi et al. \(2017\)](#) found that energy taxes do not have a significant effect on investment in environmental R & D in the private sector.

### **3.3. Empirical model**

To achieve the first goal of this chapter, we employed general specifications for the economic growth rate, total physical investment, human capital, CO<sub>2</sub> emissions and environmental innovation, drawing on a set of explanatory variables used in the existing literature. We assumed that physical investment, human capital and environmental innovation are endogenous variables in the growth equation. The other explanatory variables of growth were regarded as exogenous. As we mentioned earlier, the theoretical literature supposes that there is a direct and negative impact of energy taxes on physical investment. To test this hypothesis, we introduced a proxy of energy taxes as an exogenous variable in the physical investment equation. The theoretical models also suppose that there is an indirect effect of these taxes on human capital, through their impacts on polluting emissions. This hypothesis was tested in two steps: firstly, by examining the effect of CO<sub>2</sub> emissions (proxy of polluting emissions) on human capital; secondly, by exploring the impact of energy taxes on CO<sub>2</sub> emissions. To do this, we introduced CO<sub>2</sub> emissions as an endogenous variable in the human capital equation, and the proxy of energy taxes as an exogenous variable in the CO<sub>2</sub> equation. Finally, to test the direct effect of energy taxes on environmental innovation, the proxy of energy taxes was included as an exogenous variable in environmental innovation equation.

### Economic growth equation

$$gr_{it} = \eta_{1i} + \lambda_{1t} + \beta_{11}change\ k_{it} + \beta_{12}H_{it-1} + \beta_{13}change\ H_{it} + \beta_{14}EINNOV_{it} + \sum_{m=5}^{11} \beta_{1m} \Omega_{it}^m + \varepsilon_{1it}, \quad (3.1)$$

Where  $gr_{it}$  is the economic growth rate in the country ( $i$ ) for the year ( $t$ );  $\eta_{1i}$  and  $\lambda_{1t}$  correspond to the country-specific effect and time-specific effect, respectively; and  $k$  is a proxy of physical capital, measured in terms of gross fixed capital formation in percentage of GDP. We used the annual change in physical capital (*change k*) to capture the effect of physical capital accumulation which is considered as an engine of economic growth (Barro and Sala-i-Martin, 2004). Its coefficient is expected to be positive.  $H$  refers to the stock of human capital. Following the empirical works of Baldacci et al. (2008) and Chi (2008), the initial level of human capital ( $H_{t-1}$ ) and its annual change (*Change H*) were used to capture the effect of human capital on economic growth rates.  $EINNOV_{it}$  is an environmental innovation.  $\Omega_{it}$  indicates a set of control explanatory variables for economic growth rates which included the following variables. ( $lny_{i0}$ ) denotes the natural logarithm of GDP per capita for each country in the year 1994. ( $TLF$ ) is the total labor force growth rate. ( $exp$ ) is productive expenditure. ( $tax$ ) denotes the distortionary taxation. ( $Balance$ ) represents the fiscal balance (surplus/deficit). ( $INF$ ) is the inflation rate which is considered as a proxy of macroeconomic stability. ( $OPENG$ ) denotes trade openness of goods. It is defined as (exports plus imports of goods) in percentage of GDP. The justification of the selected control explanatory variables of economic growth rate is presented in the section 1.4.2 in the first chapter.

### Physical investment equation

The physical investment equation was used to explore the impact of energy taxes on gross physical investment (private and public investment).

$$k_{it} = \eta_{2i} + \lambda_{2t} + \beta_{21}ET_{2it} + \sum_{n=2}^6 \beta_{2n} \varphi_{it}^n + \varepsilon_{2it}, \quad (3.2)$$

Where, the gross physical investment ( $k$ ) was measured by the real gross fixed capital formation as a percentage of GDP. This variable was represented as a proxy of physical capital.  $ET_{2it}$  denotes a proxy of energy taxes. The calculation method for this proxy is explained in the section 2.4 of the second chapter.  $\varphi_{it}^n$  refers to a set of control explanatory variables of investment which are as follows: productive expenditure ( $exp$ ); distortionary-taxes ( $tax$ ); domestic credit accorded to the private sector ( $DCPS$ ); regulatory quality ( $RQ$ ); and gross national saving ( $GNS$ ).

Theoretically, productive expenditure was expected to positively affect gross investment, as it increases the productivity of capital for the private sector, thus promoting economic growth (Barro, 1990). However, this effect may vary depending on the means of funding. When productive expenditure is financed by non-distortionary tax, the effect is expected to be positive, whereas when it is financed by distortionary-tax the predicted effect is ambiguous (Kneller et al. 1999). The total tax burden (as a percentage of the GDP) is also used as a determinant of investment in empirical studies (Tadeu and Silva, 2013). However, in this chapter we followed Barro (1990) and Kneller et al. (1999) who distinguish between distortionary and non-distortionary tax. We only used the distortionary tax, which is considered to have a negative impact on saving and investment decisions. In this way, we avoided the collinearity problem that can occur between total tax burden and energy tax, as the latter is a part of the total tax burden.

According to Blejer and Khan (1984); McKinnon (2010), and Sen and Athukorala (2002), credit availability is a key factor influencing investment behavior, independent of the cost of capital. In empirical studies, credit availability is usually measured by the domestic credit accorded to the private sector (DCPS) as a percentage of GDP (Jongwanich and Kohpaiboon, 2008).

Regulatory quality is an institutional variable. “It reflects perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development” (Kaufmann et al., 2010). We considered this variable as a proxy of governance quality.

The level of gross national saving (GNS) is also considered as a main determinant of investment, where higher savings enable higher investment (Harrod, 1939).



### Human capital equation

$$H_{it} = \eta_{3i} + \lambda_{3t} + \beta_{31} \text{LogCO2}_{3it} + \sum_{l=2}^5 \beta_{2l} \pi_{it}^l + \varepsilon_{3it}, \quad (3.3)$$

Where  $H$  refers to the stock of human capital, which is proxied by the human-skill index constructed by the “Laboratoire d’Économie Appliquée au Développement (LEAD)” in Toulon University (France). Literacy rate, enrolment in tertiary education, and mean years of schooling of adults were used to construct this index based on the work of Archibugi and Coco (2004). The advantage of this indicator is that its data is annual, which allowed us to include the annual change of human capital in the model. The data of Barro and Lee (2013) did not offer this possibility as it is based on 5-year age group.

$\text{LogCO2}$  denotes the logarithm of carbon dioxide emissions,  $\pi_{it}^l$  refers to a set of control explanatory variables of human capital, which are as follows:  $exp$  denotes productive expenditure. According to the 1995 pamphlet from the IMF on unproductive public expenditures, public expenditures in basic infrastructure represent a crucial precondition for physical and human capital accumulations (Chu and International Monetary Fund, 1995). This idea is confirmed by Escobar-Posada and Monteiro (2015); FERT is the total fertility rate (births per woman). In developed countries, the increase in the rate of technological progress leads to human capital playing a greater role in the production process. This makes households favor quality of children over quantity, leading to increased investment in children’s education and to a decline in fertility rate (Galor, 2012; Hafner and Mayer-Foulkes, 2013). Therefore, the fertility rate was expected to be negatively correlated with human capital formation;  $TID$  refers to technology infrastructure development. It is measured by the technology-infrastructure index<sup>24</sup> presented by the LEAD at Toulon University. In countries with a high level of technology infrastructure development, there is easier access to communication tools, which are the main channels through which knowledge can spill over, leading to increases in human capital (Alfaro et al., 2017; Jang et al., 2017); and RQ refers to the regulatory quality.

### CO2 emissions equation

$$\text{LogCO2}_{it} = \eta_{4i} + \lambda_{4t} + \beta_{41} \text{ET}_{4it} + \sum_{r=2}^5 \beta_{2r} \rho_{it}^r + \varepsilon_{4it}, \quad (3.4)$$

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<sup>24</sup> This index has been built around four indicators: 1) Fixed broadband Internet subscribers per 100 people, 2) Telephone fixed-lines per 100 people, 3) Mobile cellular subscriptions per 100 people, 4) Electric power consumption (kWh per capita).

Where  $CO_2$  is carbon dioxide emissions stemming from the burning of fossil fuels and the manufacturing of cement. They are measured in kiloton (kt). The choice of  $CO_2$  as a proxy of pollution emissions is based on the findings of [Raymond \(2009\)](#). He found that there is a very strong correlation between the pairs  $CO_2$  &  $NO_x$ ,  $CO_2$  &  $SO_x$ ,  $NO_x$  &  $SO_x$ , and that taking one or the other gives the same results. In addition, [Rezza \(2015\)](#) showed that the use of more than one proxy to represent environmental stringency in the regression does not have a statistically significant influence on the results. Consequently, as  $CO_2$  emissions have no missing data for all OECD countries; it was chosen as a proxy of pollution emissions.  $\rho_{it}^r$  is a set of control explanatory variables of  $CO_2$  emissions, which include the variables below.

Based on the *Environmental Kuznets Curve (EKC)*, pollution emissions rise with income in early stages of economic growth. However, after a certain level of economic growth, society becomes more aware of the need to protect the environment, leading to a decline in the level of pollutant emissions. Consequently, we included GDP per capita ( $Y$ ) as a determinate of  $CO_2$  emissions in equation (3.4). In studies that seek to test the EKC hypothesis, the square of GDP per capita is included in the  $CO_2$  equation, to verify the quadratic relationship between economic growth and environmental pollution. However, in this study we did not aspire to examine the EKC hypothesis, and we identified a high correlation between the level of GDP per capita and its square, which can create a collinearity problem. Therefore, we did not include the square of GDP in equation (3.4). In keeping with [Ang \(2007\)](#), [Dogan and Seker \(2016\)](#), [Jiang and Guan \(2016\)](#), [Rüstemoğlu and Andrés \(2016\)](#), and [Shao et al. \(2011\)](#), we used energy consumption, trade openness, and population growth as determinants of carbon dioxide emissions. Concerning energy consumption, we distinguished between renewable and non-renewable energy by only including the non-renewable energy, which is the main source of  $CO_2$  emissions ([Dogan and Seker, 2016](#)). Therefore, energy consumption was measured according to the share of total final consumption of polluting energy products in the total final consumption of energy (TFCPEP\_sh). The calculation of this variable is presented in the appendix (2.A) of the second chapter. With respect to trade openness, [Dogan and Seker \(2016\)](#) found that a 1% increase in trade openness mitigated carbon emissions by 0.06%. This result can be explained by an increase the ratio of services to commodities in the trade openness index, where the production of services generates less carbon dioxide emissions than the production of goods. Consequently, we distinguished between goods and services trade by only using the trade openness of goods as  $CO_2$  emissions determinant. Consequently,

the link between this variable and CO2 emissions is expected to be positive. Finally, the emissions of carbon dioxide are expected to increase with population growth (LPOP).

### **Environmental innovation equation**

To explore the effect of energy taxes, used as an instrument in environmental policy, on environmental innovations, we constructed the following equation:

$$EINNOV_{it} = \eta_{5i} + \lambda_{5t} + \beta_{51}ET_{5it} + \sum_{v=2}^5 \beta_{5v} \varrho_{it}^v + \varepsilon_{5it}, \quad (3.5)$$

Where  $EINNOV_{it}$  refers to environmental innovation. It was measured based on the development of environment-related technologies as a percentage of all technologies. This indicator was obtained from OECD statistics on green growth. The measure of this indicator was based on patent data for about 80 environment-related technology fields (for more information please see [Haščič and Migotto \(2015\)](#)). Patent data is preferred as an alternative measure of environmental innovation to research and development expenditure data, for two main reasons. Firstly, patent data measures the output of inventive processes, while R&D data measures only the input ([OECD, 2009](#)). Secondly, as patent data provides information on the inventor(s), the nature of the invention, and the applicant, it is easy to identify environmental technologies, whereas this is more difficult with R&D expenditure data ([Haščič and Migotto, 2015](#)). The terms “environmental innovation” and “eco-innovation” are used synonymously here.  $\varrho_{it}^v$  includes the control variables that were identified in the empirical literature as being determinants of eco-innovation. It consists of four variables. Firstly, the environmentally-related government R&D budget as a percentage of total government R&D (*ERGRDB*), extracted from the OECD database. The direct financial support provided to research and development through the public sector budget is one of the most common means of encouraging inventive activity ([Hascic and Johnstone, 2011](#)). However, as our focus in this chapter is on environmental innovation, we only used the public R & D budget share allocated to support R & D activities related to the environment. Secondly, foreign direct investment (FDI) is considered as the most important and least expensive channel of direct and indirect technology transfer between countries ([Damijan et al., 2003](#); [Maskus, 2004](#)). Therefore, we used FDI as a proxy variable for external technology acquisition and the influence of exogenous technology on domestic environmental innovation levels. Thirdly, [Horbach \(2016\)](#) found that the reduction of energy use is one of the

motivations for eco-innovation. Consequently, the share of total final consumption of polluting energy products in the total final consumption of energy ( $TFCPEP_{sh}$ ) was used as a determinant of environmental innovation in equation (3.5). The level of fossil fuel consumption compared to clean energy could be a motivation for environmental innovation to reduce the additional production costs caused by energy taxes and to improve the quality of the environment at the same time. Finally, we included a measure of the intensity of the effort dedicated to innovation. This is R & D personnel intensity ( $RDPI$ ), which was calculated as follows: (total number of employees engaged in R & D, as well as those providing direct services such as R & D managers, administrators and clerical staff divided by total number of employees) $\times 100$ . This variable was expected to have a positive impact on eco-innovation (Costa-Campi et al., 2017).

The equations from (3.1) to (3.5) allowed us to answer the first question in our study. We then explored whether the effect of energy taxes on these channels, and subsequently on economic growth, is sensitive to the existence of public debt. To do this, we first determined the channel through which public debt could affect economic growth. According to the literature, public debt may hamper economic growth through its negative impact on investment. This negative effect of public debt on investment depends on who the government borrows from, and how it uses the money. When the government borrows from its citizens, using government bonds, this may absorb a portion of people's savings that would otherwise be used to finance private investment, and thus reduces economic growth (Teles and Cesar Mussolini, 2014a). Similarly, the neoclassical school of thought supposes that financing government deficit through borrowing increases the demand for money. A higher demand for money due to increased government expenditure raises the interest rates, crowding out investment and eventually lowering growth (Gogas et al., 2014; Gwartney et al., 1998; Mueller, 2004). On the other hand, if the government borrowed from other countries, a high level of public debt could increase money or cash supply, leading to an increase in inflation (Bhattarai et al., 2014), and thus harming investment and economic growth. Additionally, Chen et al. (2016) showed that when the public debt-to-GDP ratio is higher than 59.72%, the positive effect of public debt on economic growth turns into a negative effect, supposing that the excessive public debts crowd out private investment through reducing personal incomes and raising the distortionary costs of taxation. Using a panel of emerging market economies, Galstyan and Velic (2017) investigated the empirical relevance of public debt for short-run exchange rate dynamics. They found that countries with higher government debt levels tend to have more depreciated

exchange rates than those with lower debt levels. These depreciations arise as debt-intolerant locals and foreign investors flee the currency and other local assets, rebalancing their portfolios toward less risky and more liquid securities. Consequently, a possible implication of this result is that after a certain threshold, public debt can hamper investment and growth in the short term through its impact on exchange rates, whereas before that threshold the debt is less harmful.

Based on these studies, we included the public debt (*DEBT*) as an exogenous variable in the physical investment equation, and we re-estimated our model to see whether the *existence* of public debt would alter the effect of energy taxes on investment. To explore whether the effect of energy taxes on investment is sensitive to the *level* of public debt, we allowed the proxy of energy taxes to interact with the public debt variable in physical investment equation, and then we re-estimated the model. Consequently, the model had the following structures:

1. *Benchmark model*: the benchmark model controlled the interest and explanatory variables of each equation in the system, without including public debt in the physical investment equation.
2. *Model A*: in model A, we added public debt as a % of GDP (*DEBT*) to the physical investment equation in the benchmark model, with the aim of investigating whether the effect of energy taxes on physical capital, and subsequently on growth is sensitive to the *existence* of public debt.
3. *Model B*: Here, we introduced an interaction term between energy taxes (*ET*) and public debt (*DEBT*) to the physical investment equation in model A, to test whether the effect of energy taxes on physical capital and, subsequently on growth is sensitive to the *level* of public debt.

### **3.4. Data**

The dataset used in this chapter spans a period from 1994 to 2013 and comprises 31 OECD members. The three OECD countries not included in our sample are Chile, Mexico, and the United States, as there was no data on productive expenditure for them at all. In addition, Latvia, was excluded from the sample because it doesn't have data on environmentally related tax revenue. The starting and ending periods were selected according to the availability of data on energy tax revenues and other explanatory variables. The data was extracted from

various sources: (i) Government Finance Statistics (GFS) and the World Economic Outlook Database (WEOD) published by the International Monetary Fund (IMF); (ii) World Development Indicators (WDIs) and Worldwide Governance Indicators (WGIs) published by the World Bank; and (iii) the Organization for Economic Co-operation and Development (OECD). Data on human capital stock was sourced from the “Laboratoire d’Économie Appliquée au Développement (LEAD)” in Toulon University (France). A summary of variables and their sources are reported in appendix (3.A).

As mentioned above, the issue of incomplete data sets is a common encumbrance in the world of empirical economic studies which hampers scientists in their quest for obtaining unbiased results. In order to treat the missing data problem, a multiple imputation method was used in this study. The details about this method are presented in the appendix (1.B) and (1.C) of chapter (1). Table (1.1) in the first chapter shows the descriptive statistics of the variables before and after multiple imputation process. Moreover, we verified that there is no harmful multicollinearity between explanatory variables by using the Variance Inflation Factor (VIF) test for each equation in the model. The details about VIF test are reported in the appendices (3.B).

### **3.5. Endogeneity issue & proposed solution**

The issue of endogeneity is well known to economists studying growth empirics. An endogeneity problem occurs when an explanatory variable is correlated with the error term (Wooldridge, 2013). This problem is linked to many sources, such as omitted variables, measurement error, and causal simultaneity (Antonakis et al., 2010). As three of the explanatory variables in the economic growth equation, (investment, human capital and environmental innovation), were to be *simultaneously determined* with the dependent variable (economic growth rate), a correlation between these three variables and the error term of the growth equation could arise. For the same reason, the CO2 emissions variable could also be correlated with the error term of the human capital equation. Although simultaneity was the most likely candidate to cause an endogeneity problem in our model, in reality, it can be difficult to distinguish precisely between the three causes. In order to deal with the endogeneity problem, a cmp approach<sup>25</sup> would allow instrumental variables to be used, as in

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<sup>25</sup> Conditional mixed process (cmp) estimator was used to estimate the parameters of equations in this study. We talk about it in section 3.6.

the two-stage least squares (2SLS) method. In this case, *cmp* is a limited-information maximum likelihood (LIML) estimator, and only the final stage parameters are structural [Roodman \(2011\)](#). The instrumental variable must satisfy two conditions: (i) it must be uncorrelated with the error term of the structural equation; and (ii) it must be correlated with the endogenous variable ([Wooldridge, 2013](#)). These conditions allow predicted values of the endogenous variable to be uncorrelated with the error term in the first stage of estimation. Thus, the problem of endogeneity is addressed. In practice, the first condition is difficult to confirm because the error term is not observed. Consequently, researchers rely on economic theory to find instrumental variables that satisfy the first condition. The second condition can be checked by conducting F-tests on the estimators of the instrumental variables. To do this, we estimated a regression model each for *k*, *H*, *EINNOV* and *LCO2* on exogenous variables, which included instrumental variables and other exogenous variables. We then performed F-tests on the estimators of the instrumental variables, where the null hypothesis is that the estimated coefficients of the instrumental variables are jointly equal to zero. If the null hypothesis was rejected, the second condition would be satisfied and then the instruments would be validated ([Wooldridge, 2013](#)). By applying this to our model, we found that investment, human capital, and environmental innovation were endogenous variables in the growth equation, and that the CO<sub>2</sub> emissions were an endogenous variable in the human capital equation. Therefore, a good instrumental variable for investment was a variable correlated with investment and with no direct effect on the economic growth rate. Similarly, a suitable instrument for human capital was a variable correlated with human capital with no direct effect on the economic growth rate. The same criterion was applied to environmental innovation. Similarly, a good instrument for CO<sub>2</sub> emissions was a variable correlated with CO<sub>2</sub> emissions with no direct effect on human capital. Consequently, based on the economic theory, we proposed gross national saving (GNS) as an instrument for investment, total fertility rate (FERT) as an instrument for human capital, foreign direct investment (FDI) and R & D personnel intensity (RDPI) as an instrument for environmental innovation.

With regards to the H equation, the proxy of energy taxes was chosen as an instrument for carbon dioxide emissions.

The instruments satisfying the first condition were chosen theoretically, however, we also performed a statistical test proposed by [Roodman and Morduch \(2014\)](#), for testing whether instruments are correlated to the error term of a structural equation. The test results showed that the proposed instruments satisfied the first condition. The details of this test are in

appendix (3.C). To verify the second condition for instrument validity in our model, we estimated the equations of the system, and then we conducted an F-test on the instruments to see whether they were jointly significant. In other words, we examined whether GNS in the k equation, FERT in the H equation, FDI and RDPI in the EINNOV equation, and ET in the LCO2 equation were jointly significant. The F-test results are presented in [table 3.1](#). They show that the five instruments were jointly significant. Therefore, the second condition was satisfied and the instruments were valid.

Null hypothesis	
(1)	[k]GNS = 0
(2)	[H]FERT = 0
(3)	[EINNOV]FDI=0
(4)	[EINNOV]RDPI=0
(5)	[LCO2]ET = 0
	F( 5,54064.3) = 9.50
	Prob > F = 0.0000

*Table 3.1: F-test results*

### 3.6. Model Estimations

To estimate the equation's coefficients, we used the conditional mixed process (cmp) estimator developed by [Roodman \(2011\)](#). This approach is suitable for estimating simultaneous equations models (SEMs) satisfying two conditions:

- (i) *“Recursivity, meaning that the equations can be arranged so that the matrix of coefficients of the endogenous variables in one another's equations is triangular. Recursive models have clearly defined stages with one or more equations in each stage.*
- (ii) *Full observability, meaning that endogenous variables appear on the right sides of equations only as observed” [Roodman \(2011, pp 160\)](#).*

As our model satisfied these two conditions, a cmp approach was adopted to estimate the equation parameters. In the context of panel data, the treatment of the individual effects, as fixed or random, is an important issue. These two kinds of effects could be added to the (SEM) and estimated by cmp. However, [Baltagi \(2008\)](#) shows that when a study focuses on a specific set of N countries, the fixed effects specification is more appropriate than random effects. As this study focuses exclusively on a sample of OECD countries, we chose to treat individual effects as fixed.



With regards to the identification issue, the estimation of the parameters of a simultaneous equations model requires two conditions: order and e rank condition. The appendix (3.D) shows that the model satisfies both conditions.

Concerning the inference of estimated coefficients, if there is a correlation between one of the explanatory variables (X for example) and the error term (endogeneity problem), the empirical relationship between the explanatory variable and the dependent variable (Y) does not identify a causal effect of X on Y, because the variation in X also moves the conditional mean of the error term (Heckman, 2008). As the cmp approach can treat endogeneity problems by using instrumental variables, the estimated coefficients could be used to capture the causal effect of explanatory variables on dependent variables. (Heckman, 2008) shows that the models that use particular methods of estimation (e.g., matching or instrumental variable estimation) are associated with a “causal inference”.

## **3.7. Results and discussion**

### **3.7.1. In the short term**

Firstly, table 3.2 presents the estimation results of “*atanhrho*” for each pair of equations in the benchmark model. The coefficient of “*atanhrho*” shows the correlation between the error terms of each pair of equations in the model (Roodman, 2011). The numbers 1, 2, 3, 4, and 5 represent the equations of economic growth rate, physical investment, human capital, CO2 emissions and environmental innovation respectively. The results reveal that the error term of the economic growth equation is correlated with the error term of each of the other equations in the model. In addition, the error term of the human capital equation is associated with the error term of the CO2 emissions equation and the environmental innovation equation. Finally, the error term of the CO2 equation is correlated with the error term of the environmental innovation equation. These results imply that the equations should be estimated as a system rather than separately.

The short term results for economic growth, physical investment, human capital, CO2 emissions, and environmental innovation are presented in table 3.3. The *benchmark model* shows estimation results without including the public debt in the model. Model A reports estimation results when the public debt is included in the physical investment equation. Model B presents the findings when we allow energy taxes (ET) to interact with public debt (DEBT) in the physical investment equation.

	Coef.
atanrho_12	0.088**
	(0.046)
atanrho_13	-0.243***
	(0.079)
atanrho_14	-0.127***
	(0.045)
atanrho_15	1.261***
	(0.272)
atanrho_23	0.017
	(0.043)
atanrho_24	-0.010
	(0.046)
atanrho_25	0.034
	(0.043)
atanrho_34	0.512***
	(0.064)
atanrho_35	-0.122***
	(.043)
atanrho_45	-0.131***
	(0.042)

Note: \*, \*\*, and \*\*\* indicates the significance level at 10, 5, and 1% respectively.

*Table 3.2: atanrho results*

(i) *Economic growth equation*

The physical capital accumulation appears to positively contribute to the economic growth rate in the benchmark model. An increase of one percent in the change of physical capital is shown to increase growth rate by 0.186 percent. However, when the public debt is included in the model (model A), or when we allow energy taxes to interact with public debt (model B), the effect of the physical capital accumulation on the economic growth rate decreases to 0.182 and 0.183 percent respectively. This can be explained by the negative effect of public debt on physical investment (see the estimation results of the physical capital equation), which weakens the role of physical capital in promoting growth. As [Romer \(1986, 1990\)](#) and [Lucas \(1988\)](#) predicted, the initial level of human capital and its annual changes are significant and positively related to the economic growth rate in the benchmark model. Model A and model B show that this positive impact of human capital on the economic growth rate decreases when public debt is included in the model and/or when energy taxes interact with public debt in the physical investment equation. This implies that the public debt through its negative impact on the physical investment also weakens the role of human capital in promoting growth.

Reducing physical investment can lead to a reduction in the number of schools and physical materials necessary for the education process, thereby reducing the contribution of human capital to stimulating growth. Environmental innovation is shown to be negatively associated with economic growth in the short term for the three models. This result is logical as the measure of environmental innovation in this study is based on patent data. A patent may need some time to become applicable in the production process and support economic growth. We can clearly see in table (3.4) that environmental innovation appears to be positively correlated with economic growth when we use lagged values for two and three years. As the estimation results of the other explanatory variables of economic growth rate are almost identical in the three models, we move on to discuss the results presented in model B. Productive expenditure is negatively correlated with the economic growth rate. As we mentioned in the first and second chapter, this result is consistent with some empirical studies that found that government spending can undermine economic performance due to inefficient use of money (Alesina et al., 2002) and/ or due to “resource displacement” (Ramey, 2011). When the government spends money, it uses labor and/or capital resources, which are then no longer available for private sector use. Other key policy-related variables also affect growth. The fiscal balance and the trade openness of goods have a positive impact on the economic growth rate, while the inflation rate shows a negative effect.

(ii) *Physical investment equation*

The results indicate that energy taxes negatively affect physical investment. A 1 US \$ increase per ton of oil equivalent of fossil fuel energy use is associated with a 0.6 percent decrease in physical investment over the year when public debt is ignored<sup>26</sup>. This negative effect increases to 0.7 percent when public debt is included in the investment equation. Moreover, the interaction term between energy taxes and public debt has a negative and significant coefficient, meaning that the effect of energy taxes on physical investment is negatively sensitive to the level of public debt. In other words, the higher the level of public debt, the

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<sup>26</sup> When the independent variable (the proxy of energy taxes) is measured in units while the dependent variable (the investment) is measured in percent or in log transformation, the interpretation of the independent variable coefficient is as follows: one unit increase in the independent variable is associated with a (independent variable coefficient \* 100) percent increase in the independent variable, whereas all other variables in the model remain constant. See: <https://stats.idre.ucla.edu/sas/faq/how-can-i-interpret-log-transformed-variables-in-terms-of-percent-change-in-linear-regression/>

more the increase in energy taxes harms physical investment in the short term. Based on these findings, we can confirm that the assumption that energy taxes harm economic growth through a negative impact on physical investment (physical capital) is valid in the short term. In addition, we can say that the theoretical models studying the effect of energy taxes on investment or economic growth must include public debt in their analysis, because the effect of energy taxes on investment, and subsequently on economic growth, is sensitive to the existence and level of public debt. For this reason, we continue to discuss the estimation results for the other investment determinants resulting from model B. In keeping with expectations, public debt shows a negative impact on investment; whereas the domestic credit accorded to the private sector as a percentage of GDP and the regulatory quality have a positive effect.

(iii) *Human capital equation*

As public debt is only included in the physical investment equation, it does not affect the estimation results for the human capital, CO<sub>2</sub> emissions and environmental innovation equations. Given that the results of the three models in the table (3.3) are almost identical for these equations, we only discuss the results presented for each one in model B. The results of the human capital equation show that the growth of carbon dioxide emissions has a negative effect on human capital. A one percent increase in the level of CO<sub>2</sub> emissions is associated with a 0.0008 unit decrease in human capital skills. This is an important and unprecedented result; to our knowledge no empirical work has tested the effect of CO<sub>2</sub> emissions on human capital skills by using panel data. This result made us wonder on the effect of the *stock* of CO<sub>2</sub> on human capital. To answer this question, we generated a new variable that measures accumulated CO<sub>2</sub> emissions (ACO<sub>2</sub>), where the level of CO<sub>2</sub> in each year is the level of CO<sub>2</sub> emissions flux in this year plus the CO<sub>2</sub> flux in the previous years. We then replaced CO<sub>2</sub> by ACO<sub>2</sub> in the model and re-estimated the coefficients in the short and long-term. Estimation results are presented in the appendix (3.H). We found that the increase of accumulated CO<sub>2</sub> emissions level has a negative impact on human capital. This result is in line with [Allen et al., \(2016\)](#). The other determinants of human capital perform as expected. While fertility rate has a negative impact, productive expenditure, technology infrastructure development, and regulatory quality are found to be positively correlated with human capital. These results are consistent with the expectations of [Escobar-Posada and Monteiro \(2015\)](#); [Galor \(2012\)](#); [Hafner and Mayer-Foulkes \(2013\)](#); [Alfaro et al. \(2017\)](#); and [Jang et al. \(2017\)](#).

(iv) *CO2 emissions equation*

The results of model B reveal that energy taxes exert a negative significant influence on CO2 emissions. A 1 US \$ increase per ton of oil equivalent of fossil fuel energy use is associated with a 0.02 percent decrease in CO2 emissions. This finding means that the tax is an efficient tool used by the government to reduce pollutant emissions. Based on these results and on the finding that an increase in both flux and stock of CO2 emissions has a negative impact on human capital- as shown in the human capital equation- we can confirm the hypothesis that pollution taxes have an indirect effect on human capital, through their impact on CO2 emissions in the short term.

Concerning the control variables, firstly, we can see that GDP per capita ( $Y$ ) is positively related with Log CO2. A one unit increase in GDP per capita is associated with a 0.06 percent increase in CO2 emissions. Secondly, the share of total final consumption of polluting energy products in total final consumption of energy appears to be positively correlated with logCO2 emissions. A one percent increase in (TFCPEP\_sh) is associated with a 0.009 percent increase in CO2 emissions. Thirdly, population growth is found to be positively related to CO2 emissions. A one percent increase in the population is associated with a 1.378 percent increase in CO2 emissions. Finally, the trade openness of goods has a positive effect on carbon dioxide emissions. A one percent increase in OPENG is associated with a 0.0006 percent increase in CO2 emissions.

(v) *Environmental innovation equation*

The empirical findings show that energy taxes have a positive and significant impact on environmental innovation. A one unit increase in the proxy of energy taxes is associated with a 0.6 percent increase in the development of environment-related technologies. We can thus conclude that the assumption that energy taxes encourage eco-innovation is valid in the short term. The coefficient of foreign direct investment is significant and positive. A one percent increase in FDI increases environmental innovation by 0.01 percent. This is in line with the results of [Damijan et al. \(2003\)](#) and [Maskus \(2004\)](#). The R & D personnel intensity is found to be positively associated with environmental innovation. A one percent increase in RDPI is associated with about a two percent increase in the development of environment-related technologies. This result is consistent with the findings of [Costa-Campi et al. \(2017\)](#).

	<i>Benchmark</i>	<i>Alternative specification</i>	
	<i>model</i>	<i>Model A</i>	<i>Model B</i>
<b>Economic growth equation</b>	Annual percentage growth rate of GDP per capita		
Change k	<b>0.168***</b> (0.054)	<b>0.162***</b> (0.055)	<b>0.163***</b> (0.055)
Ht-1	<b>43.328**</b> (18.88)	<b>39.877**</b> (18.932)	<b>39.303**</b> (18.910)
Change H	<b>67.974***</b> (21.865)	<b>64.716***</b> (21.860)	<b>64.014**</b> (21.824)
EINNOV	<b>-1.171***</b> (0.388)	<b>-1.168***</b> (0.395)	<b>-1.158**</b> (0.382)
lnY0	-1.208 (1.752)	-1.337 (1.745)	-1.333 (1.748)
TLF	3.492 (7.936)	4.140 (7.944)	4.136 (7.946)
exp	<b>-0.369***</b> (0.084)	<b>-0.361***</b> (0.084)	<b>-0.360***</b> (0.084)
tax	-0.047 (0.071)	-0.047 (0.071)	-0.047 (0.071)
Balance	<b>0.082**</b> (0.038)	<b>0.088**</b> (0.038)	<b>0.088**</b> (0.038)
INF	<b>-0.040**</b> (0.018)	<b>-0.041**</b> (0.019)	<b>-0.041**</b> (0.019)
OPENG	<b>0.033***</b> (0.008)	<b>0.034***</b> (0.008)	<b>0.034***</b> (0.008)
<b>Physical investment equation</b>	Real gross fixed capital formation as a percentage of GDP		
ET	<b>-0.006***</b> (0.002)	<b>-0.007***</b> (0.001)	<b>-0.005**</b> (0.002)
DEBT		<b>-0.056***</b> (0.007)	<b>-0.043***</b> (0.011)
ET#DEBT			<b>-0.0001*</b> (0.000)
exp	-0.106 (0.093)	-0.052 (0.092)	-0.057 (0.092)
tax	<b>-0.154**</b> (0.074)	0.010 (0.074)	0.018 (0.074)
DCPS	<b>0.029***</b> (0.004)	<b>0.017***</b> (0.004)	<b>0.017***</b> (0.004)
RQ	<b>4.327***</b> (0.759)	<b>3.109***</b> (0.760)	<b>2.853***</b> (0.775)
GNS	<b>0.090**</b> (0.038)	-0.007 (0.038)	-0.018 (0.039)
<b>Human capital equation</b>	Human-skill index		
LCO2	<b>-0.077**</b> (0.011)	<b>-0.076***</b> (0.010)	<b>-0.076***</b> (0.010)
exp	<b>0.001**</b> (0.001)	<b>0.001**</b> (0.001)	<b>0.001**</b> (0.0005)
FERT	<b>-0.024***</b> (0.006)	<b>-0.024***</b> (0.006)	<b>-0.024***</b> (0.006)
TID	<b>0.128***</b> (0.026)	<b>0.132***</b> (0.026)	<b>0.132***</b> (0.026)
RQ	<b>0.012***</b>	<b>0.012***</b>	<b>0.012***</b>

	<i>Benchmark model</i>	<i>Alternative specification</i>	
	(0.005)	<i>Model A</i> (0.005)	<i>Model B</i> (0.004)
<b>CO2 equation</b>	Logarithm of carbon dioxide emissions		
ET	<b>-0.0002***</b> (0.000)	<b>-0.0002***</b> (0.000)	<b>-0.0002***</b> (0.000)
Y	<b>0.0006***</b> (0.0001)	<b>0.0006***</b> (0.0001)	<b>0.0006***</b> (0.0001)
TFCPEP_sh	<b>0.0099***</b> (0.001)	<b>0.0098***</b> (0.001)	<b>0.0097***</b> (0.001)
LPOP	<b>1.382***</b> (0.093)	<b>1.380***</b> (0.093)	<b>1.378***</b> (0.093)
OPENG	<b>0.0006**</b> (0.0002)	<b>0.0006**</b> (0.0002)	<b>0.0006**</b> (0.0002)
<b>Environmental innovation equation</b>	Development of environment-related technologies		
ET	<b>0.006***</b> (0.001)	<b>0.006***</b> (0.001)	<b>0.006***</b> (0.001)
ERGRDB	-0.070 (0.062)	-0.071 (0.062)	-0.070 (0.062)
FDI	<b>0.010**</b> (0.005)	<b>0.010**</b> (0.005)	<b>0.010**</b> (0.005)
TFCPEP_sh	-0.043 (0.034)	-0.039 (0.034)	-0.040 (0.034)
RDPI	<b>1.675**</b> (0.683)	<b>1.682**</b> (0.689)	<b>1.696**</b> (0.687)
Observations	620	620	620
Number of countries	31	31	31

Note: \*, \*\*, and \*\*\* indicates the significance level at 10, 5, and 1% respectively based on the two-tailed test. Standard error estimates are in parentheses. The country-specific effect ( $\eta_i$ ), the time-specific effect ( $\lambda_t$ ), and the constant were included in the regressions of each equation in the model but they are not presented in this table.

*Table 3.3: Estimation results in the short term*

### 3.7.2. In the long term

In order to investigate the potential impact of energy taxes on physical investment, human capital and environmental innovation over the long term, and to know whether this impact is sensitive to the existence and level of public debt, the system of equations was re-estimated with lagged values for all explanatory variables for five one-year periods. This method was used to reveal whether the revenues from energy taxes per ton of oil equivalent of fossil fuel energy use generated in previous years had an impact on the endogenous variables in the current year. The results are presented in tables (3.4) and (3.5). Table (3.4) shows the estimation results for the three models (benchmark model, model A and model B), when *lags*

are equal to 1, 2 and 3 years. The table (3.5) presents the findings for the three models when lags are equal to 4 and 5 years.

(i) *Economic growth equation*

Focusing on the endogenous variables of the growth equation, firstly, the *benchmark model* shows that the accumulation of physical capital (*change k*) has a positive impact on the economic growth rate at one lag year. However, when public debt is included in the model (model A) or when energy taxes interact with public debt (model B), this positive impact of (*change k*) decreases from 1.81 percent to 1.58 and 1.54 percent respectively. The negative effect of public debt on physical investment (see the results of the physical investment equation) can explain why the contribution of (*change k*) to promoting growth decreased with the presence of public debt in model A and model B. Secondly, the change in human capital is found to be positively associated with the economic growth rate in the first lagged year, and negatively correlated with the economic growth rate in the fourth lagged year. Similarly, environmental innovation shows a positive impact on the economic growth rate when the explanatory variables are lagged for two and three years. This effect becomes negative when the number of lagged years equals to five. This may reflect a U relationship between the change in human capital skill and the economic growth rate and between environmental innovation and the economic growth rate in the long term. This is possible because some of the skills that have been learned over four years or the technology that has been innovated over five years, may be not usable in the current year, or usable but with low productivity, especially in view of the rapid technological and cognitive progress seen in recent years.

Concerning the exogenous variables of economic growth equation, total labor force growth is found to be negatively associated with economic growth in the second and the third lag years. As we mentioned in the first and second chapter, this could be due to the very stable nature of the labor force across the OECD countries, compared with the labor force in developing economies. In line with the results of [Alesina et al. \(2002\)](#) and [Ramey \(2011\)](#), the productive expenditure is appeared to be negatively correlated with the economic growth rate in the first lagged year. Other results indicate that the inflation rate enters regressions with a negative impact on economic growth at one, two and three lag years. Finally, the trade openness of goods positively affects the economic growth rate for the first three lagged years.



(ii) *Physical investment equation*

The benchmark model of each lag shows that energy taxes have a significant and negative effect on physical investment. This result allows us to confirm the validity of the assumption that energy taxes harms physical investment (physical capital) over the long term. When we include public debt in the physical investment equation, the negative impact of energy taxes on investment increases by (0.01%) at one, two and three lag years (see model A for each lag). However with the last two lagged years, the magnitude of the energy taxes' coefficient does not show any change when we add public debt to investment regression. The other results for *model A* in each lag shows that public debt negatively affects physical investment for the five lagged years. The interaction term between energy taxes and public debt, in *model B*, has a significant and negative sign for the first three lagged years. This means that, in the long term (three years), the effect of energy taxes on physical investment is negatively sensitive to the level of public debt. In other words, if a country has a high level of public debt, the negative effect of energy taxes on investment is greater than for a country with a low level of public debt. These results could be used to make insightful recommendations to policymakers, especially for governments that are planning or implementing environmental tax reforms. Using a part of energy tax revenues to reduce public debt levels could decrease the negative effects of public debt and energy taxes on physical investments over the short and long term.

The other determinants of investment are discussed based on *model B* for each lag. Productive expenditure is found to be negatively associated with physical investment in the first two lagged years. As mentioned earlier, this negative impact can occur due to inefficient use of money (Alesina et al., 2002) and/ or due to “resource displacement” (Ramey, 2011). The domestic credit accorded to the private sector has a positive effect on investment at one lag year and a negative impact at four and five lag years. These results can be linked to the findings of Samargandi (2015). The increase in credit, along with a lack of regulatory control and monitoring from the bankers, may result in an inappropriate selection of projects (Sundararajan and Baliño, 1991) and an engagement in non-operating activities, ultimately leading to stagnant levels of physical investment (Tori and Onaran, 2017). Regulatory quality is found to be positively related to investment in the first three lagged years. Finally, gross national savings have a positive effect on investment at 2-5 lag years.

(iii) *Human capital equation*

As public debt and its interaction with energy taxes are only included in the physical investment equation, it only affects the estimation results for the physical investment and economic growth equations. The estimation results for the human capital, CO<sub>2</sub> emissions, and eco-innovation equations are almost identical in the three models for each lag. Therefore, we discuss only the results of the model B of each lag for these three equations.

The logarithm of carbon dioxide emissions has a negative effect on human capital for lags 1-3. This implies that the increase in the level of CO<sub>2</sub> emissions during the previous three years negatively affects the human capital skill in the current year. In addition, estimation results reported in the appendix (3.H), which show the results when ACO<sub>2</sub> was used instead of CO<sub>2</sub>, indicate to a negative impact of the logarithm of accumulated carbon dioxide emissions on human capital at lags 1-4. The fertility rate also appears to be negatively associated with human capital for lags 1-3. In contrast, productive expenditure is positively correlated with human capital in the first three lagged years. As expected, technology infrastructure development has a positive effect on human capital over the five lagged periods. Finally, regularity quality is only found to be positively correlated to human capital in the first lagged year.

(iv) *CO<sub>2</sub> emissions equation*

The empirical results reveal that energy taxes have a negative impact on CO<sub>2</sub> emission at one and two lag years. This means that the revenues from energy taxes per ton of oil equivalent of fossil fuel use generated over the two previous years can reduce the CO<sub>2</sub> emissions in the current year. Based on this result and the finding that CO<sub>2</sub> emissions negatively affect human capital skills for three lagged years, we conclude that the assumption that there is an indirect effect of pollution taxes on human capital, through their impacts on CO<sub>2</sub> emissions is valid over the long term.

With regards to the other control variables of the CO<sub>2</sub> emissions logarithm, we found that the GDP per capita, the share of total final consumption of polluting energy products in total energy use, and the population growth have a positive effect on CO<sub>2</sub> emissions for lags 1-5. The trade openness of goods also shows a positive impact on the carbon dioxide emission but only for lags 1-4.

(v) *Environmental innovation equation*

Our study found that energy taxes have a significant and positive effect on environmental innovation for the five lagged years. This means that the revenue from energy taxes per ton of oil equivalent of fossil fuel use generated over each of the previous five years encourages the development of environment-related technologies in the current year. This result is very important and unprecedented, because it represents the first empirical evidence at a macroeconomic level of the effect of energy taxes on eco-innovation in the long term. Consequently, we can confirm the validity of the assumption that energy taxes encourage eco-innovation in the long term.

As for the results of the other determinants of eco-innovation, the environmentally related government R&D budget as a percent of total government R&D (ERGRDB) only shows a positive impact on environmental innovation at two lag years. The magnitude of the positive effect of (ERGRDB) is higher than that of energy taxes when the explanatory variables are lagged for two years. We conclude that after two lagged years, the direct financial support provided to environmental research and development can be more effective than energy taxes for promoting eco-innovation. However, the positive effect of energy taxes on eco-innovation is more sustainable than direct financial support in the long term. This leads us to the conclusion that both the tax and the subsidy are two important instruments of environmental policy for encouraging eco-innovation in the long term. Here, it should be noted that the public R & D budget share allocated to support R & D activities related to the environment is relatively small. The average of this share represents only 2.8% of total government R&D expenditure in the OECD zone. Despite this small share, a positive impact on eco-innovation can be observed at two lagged years. This result is very important for policymakers, as the increase of this share alongside energy taxes could significantly promote environmental innovation in the long term. Finally, while the share of total final consumption of polluting energy products in total energy use has a negative impact on environmental innovation for the first and second lags, we found that the R & D personnel intensity positively affects the development of environment-related technologies at one and three lag years.

	<i>Lags=1</i>			<i>Lags=2</i>			<i>Lags=3</i>		
	<i>Benchmark model</i>	<i>Alternative specification</i>		<i>Benchmark model</i>	<i>Alternative specification</i>		<i>Benchmark model</i>	<i>Alternative specification</i>	
		<i>Model A</i>	<i>Model B</i>		<i>Model A</i>	<i>Model B</i>		<i>Model A</i>	<i>Model B</i>
<b>Economic growth equation</b>	Annual percentage growth rate of GDP per capita								
Change k	<b>0.181***</b> (0.065)	<b>0.158**</b> (0.066)	<b>0.154**</b> (0.066)	-0.064 (0.066)	-0.090 (0.067)	-0.095 (0.067)	0.005 (0.062)	-0.005 (0.062)	-0.009 (0.062)
Ht-1	-0.170 (10.138)	-1.941 (10.152)	-2.100 (10.145)	-12.251 (8.373)	-13.639 (8.312)	-13.847 (8.292)	-4.834 (7.205)	-5.431 (7.165)	-5.544 (7.158)
Change H	<b>28.718**</b> (14.721)	<b>27.905*</b> (14.674)	<b>27.742*</b> (14.662)	-15.416 (13.587)	-16.363 (13.473)	-16.9100 (13.449)	10.787 (12.509)	15.939 (11.473)	15.697 (11.456)
EINNOV	0.032 (0.035)	0.035 (0.035)	0.035 (0.035)	<b>0.094***</b> (0.036)	<b>0.097***</b> (0.036)	<b>0.097***</b> (0.036)	<b>0.099***</b> (0.037)	<b>0.098***</b> (0.037)	<b>0.098***</b> (0.037)
lnY0	-1.442 (2.543)	-1.498 (2.529)	-1.466 (2.528)	3.644 (2.565)	4.001 (2.552)	4.046 (2.548)	2.284 (2.344)	2.438 (2.334)	2.454 (2.333)
TLF	-0.289 (8.566)	0.989 (8.566)	1.247 (8.568)	<b>-25.61***</b> (9.059)	<b>-23.40***</b> (9.041)	<b>-22.891**</b> (9.041)	<b>-31.198***</b> (9.121)	<b>-29.718***</b> (9.093)	<b>-29.417***</b> (9.082)
exp	<b>-0.139*</b> (0.084)	<b>-0.139*</b> (.084)	<b>-0.139*</b> (0.084)	-0.090 (0.086)	-0.088 (0.086)	-0.089 (0.086)	-0.093 (0.087)	-0.088 (0.087)	-0.087 (0.087)
tax	-0.027 (0.072)	-0.024 (0.072)	-0.025 (0.072)	-0.080 (0.076)	-0.076 (0.076)	-0.077 (0.076)	-0.072 (0.077)	-0.071 (0.077)	-0.074 (0.077)
Balance	0.014 (0.040)	0.015 (0.04)	0.014 (0.040)	0.016 (0.042)	0.020 (0.042)	0.019 (0.042)	-0.046 (0.043)	-0.0418 (0.043)	-0.040 (0.043)
INF	<b>-0.046**</b> (0.015)	<b>-0.049***</b> (0.015)	<b>-0.049***</b> (0.015)	<b>-0.039***</b> (0.016)	<b>-0.043***</b> (0.016)	<b>-0.043***</b> (0.016)	<b>-0.042**</b> (0.016)	<b>-0.044***</b> (0.016)	<b>-0.044***</b> (0.016)
OPENG	<b>0.032***</b> (0.009)	<b>0.0341***</b> (0.009)	<b>0.034***</b> (0.009)	<b>0.017*</b> (0.010)	<b>0.019**</b> (0.010)	<b>0.019**</b> (0.010)	<b>0.017*</b> (0.010)	<b>0.018*</b> (0.010)	<b>0.018*</b> (0.010)
<b>Physical investment equation</b>	Real gross fixed capital formation as a percentage of GDP								
ET	<b>-0.007***</b> (0.002)	<b>-0.008***</b> (0.001)	<b>-0.005***</b> (0.002)	<b>-0.009***</b> (0.002)	<b>-0.01***</b> (0.002)	<b>-0.006**</b> (0.002)	<b>-0.011***</b> (0.002)	<b>-0.012***</b> (0.002)	<b>-0.008***</b> (0.002)
DEBT		<b>-0.052***</b> (0.008)	<b>-0.032***</b> (0.011)		<b>-0.049***</b> (0.009)	<b>-0.025**</b> (0.012)		<b>-0.040***</b> (0.009)	<b>-0.018***</b> (0.013)
ET#DEBT			<b>-0.0001**</b> (0.000)			<b>-0.0001***</b> (0.000)			<b>-0.0001***</b> (0.000)
exp	<b>-0.207**</b> (0.091)	<b>-0.155*</b> (0.091)	<b>-0.164*</b> (0.091)	<b>-0.254***</b> (0.094)	<b>-0.203**</b> (0.094)	<b>-0.211**</b> (0.093)	<b>-0.161*</b> (0.093)	-0.120 (0.095)	-0.125 (0.094)
tax	<b>-0.157**</b> (0.077)	-0.016 (0.077)	-0.003 (0.076)	<b>-0.152*</b> (0.078)	-0.039 (0.078)	-0.025 (0.078)	<b>-0.153**</b> (0.078)	-0.065 (0.079)	-0.047 (0.079)
DCPS	<b>0.026***</b> (0.004)	<b>0.015***</b> (0.004)	<b>0.015***</b> (0.004)	<b>0.016***</b> (0.004)	0.006 (0.004)	0.006 (0.004)	0.005 (0.004)	-0.0002 (0.004)	-0.003 (0.004)
RQ	<b>4.345***</b> (0.747)	<b>3.355***</b> (0.746)	<b>3.028***</b> (0.759)	<b>3.747***</b> (0.748)	<b>2.955***</b> (0.749)	<b>2.644***</b> (0.755)	<b>2.466***</b> (0.761)	<b>2.009***</b> (0.757)	<b>1.822**</b> (0.757)
GNS	<b>0.166***</b> (0.039)	<b>0.074*</b> (0.040)	0.058 (0.040)	<b>0.205***</b> (0.040)	<b>0.123***</b> (0.042)	<b>0.109***</b> (0.042)	<b>0.295***</b> (0.041)	<b>0.239***</b> (0.043)	<b>0.232***</b> (0.043)
<b>Human capital equation</b>	Human-skill index								
LCO2	<b>-0.046***</b> (0.008)	<b>-0.045***</b> (0.008)	<b>-0.045***</b> (0.008)	<b>-0.026***</b> (0.008)	<b>-0.025***</b> (0.008)	<b>-0.025***</b> (0.008)	<b>-0.021***</b> (0.008)	<b>-0.021***</b> (0.008)	<b>-0.021***</b> (0.008)
exp	<b>0.001**</b> (0.0005)	<b>0.001**</b> (0.0005)	<b>0.001**</b> (0.0005)	<b>0.001*</b> (0.0005)	<b>0.001*</b> (0.0005)	<b>0.001*</b> (0.0005)	<b>0.001*</b> (0.0005)	0.001 (0.0005)	<b>0.001*</b> (0.0005)
FERT	<b>-0.019***</b> (0.006)	<b>-0.019***</b> (0.006)	<b>-0.019***</b> (0.006)	<b>-0.012*</b> (0.006)	<b>-0.012*</b> (0.006)	<b>-0.012*</b> (0.006)	<b>-0.010*</b> (0.007)	-0.010 (0.006)	<b>-0.010*</b> (0.006)
TID	<b>0.134***</b> (0.028)	<b>0.136***</b> (0.028)	<b>0.134***</b> (0.028)	<b>0.130***</b> (0.028)	<b>0.130***</b> (0.028)	<b>0.130***</b> (0.028)	<b>0.118***</b> (0.028)	<b>0.119***</b> (0.028)	<b>0.118***</b> (0.028)

	<i>Lags=1</i>			<i>Lags=2</i>			<i>Lags=3</i>		
	<i>Benchmark model</i>	<i>Alternative specification</i>		<i>Benchmark model</i>	<i>Alternative specification</i>		<i>Benchmark model</i>	<i>Alternative specification</i>	
		<i>Model A</i>	<i>Model B</i>		<i>Model A</i>	<i>Model B</i>		<i>Model A</i>	<i>Model B</i>
RQ	<b>0.008*</b> (0.005)	<b>0.008*</b> (0.005)	<b>0.008*</b> (0.005)	0.003 (0.004)	0.003 (0.004)	0.003 (0.004)	0.006 (0.005)	0.006 (0.005)	0.005 (0.005)
<b>CO2 equation</b>	Logarithm of carbon dioxide emissions								
ET	<b>-0.0002***</b> (0.0001)	<b>-0.0002***</b> (0.0001)	<b>-0.0002***</b> (0.0001)	<b>-0.0002**</b> (0.0001)	<b>-0.0002**</b> (0.0001)	<b>-0.0002**</b> (0.0001)	-0.0001 (0.000)	-0.0001 (0.000)	-0.0001 (0.000)
Y	<b>0.00001***</b> (0.0001)	<b>0.00001***</b> (0.0001)	<b>0.00001***</b> (0.0001)	<b>0.00001***</b> (0.0001)	<b>0.00001***</b> (0.0001)	<b>0.00001***</b> (0.0001)	<b>0.00001***</b> (0.0001)	<b>0.00001***</b> (0.0001)	<b>0.00001***</b> (0.0001)
TFCPEP_sh	<b>0.009***</b> (0.001)	<b>0.009***</b> (0.001)	<b>0.009***</b> (0.001)	<b>0.008***</b> (0.001)	<b>0.008***</b> (0.001)	<b>0.008***</b> (0.001)	<b>0.007***</b> (0.001)	<b>0.007***</b> (0.001)	<b>0.007***</b> (0.001)
Lpop	<b>1.343***</b> (0.100)	<b>1.343***</b> (0.100)	<b>1.343***</b> (0.100)	<b>1.233***</b> (0.109)	<b>1.233***</b> (0.109)	<b>1.233***</b> (0.109)	<b>1.094***</b> (0.116)	<b>1.095***</b> (0.116)	<b>1.098***</b> (0.116)
OPENG	<b>0.0007**</b> (0.0003)	<b>0.0007**</b> (0.0003)	<b>0.0007**</b> (0.0003)	<b>0.0008**</b> (0.0003)	<b>0.0008**</b> (0.0003)	<b>0.0007**</b> (0.0003)	<b>0.0009***</b> (0.0003)	<b>0.001***</b> (0.0003)	<b>0.0009***</b> (0.0003)
<b>Environmental innovation equation</b>	Development of environment-related technologies								
ET	<b>0.005**</b> (0.002)	<b>0.005**</b> (0.002)	<b>0.005**</b> (0.002)	<b>0.006**</b> (0.003)	<b>0.006**</b> (0.003)	<b>0.006**</b> (0.003)	<b>0.007***</b> (0.002)	<b>0.007***</b> (0.002)	<b>0.007***</b> (0.002)
ERGRDB	0.131 (0.102)	0.131 (0.102)	0.131 (0.102)	<b>0.180*</b> (0.102)	<b>0.183*</b> (0.014)	<b>0.184*</b> (0.014)	0.142 (0.097)	0.144 (0.097)	0.144 (0.097)
FDI	-0.003 (0.009)	-0.003 (0.009)	-0.003 (0.009)	-0.007 (0.014)	-0.006 (0.014)	-0.006 (0.014)	-0.001 (0.014)	-0.001 (0.014)	-0.001 (0.014)
TFCPEP_sh	<b>-0.087*</b> (0.051)	<b>-0.088*</b> (0.051)	<b>-0.087*</b> (0.051)	<b>-0.117**</b> (0.053)	<b>-0.118**</b> (0.053)	<b>-0.117**</b> (0.053)	-0.050 (0.058)	-0.051 (0.058)	-0.051 (0.058)
RDPI	<b>1.619*</b> (0.926)	<b>1.621*</b> (0.926)	<b>1.615*</b> (0.926)	1.301 (0.933)	1.310 (0.933)	1.320 (0.933)	<b>1.674*</b> (1.036)	<b>1.681*</b> (1.036)	<b>1.695*</b> (1.036)
Observations	589	589	589	558	558	558	527	527	527
Number of countries	31	31	31	31	31	31	31	31	31

Note: \*, \*\*, and \*\*\* indicates the significance level at 10, 5, and 1% respectively based on the two-tailed test. Standard error estimates are in parentheses. The country-specific effect ( $\eta_i$ ), the time-specific effect ( $\lambda_t$ ), and the constant were included in the regressions of each equation in the model but they are not presented in this table.

*Table 3.4: Estimation results in the long term (number of lagged years equals to 1, 2 and 3)*

	<i>Lags=4</i>			<i>Lags=5</i>		
	<i>Benchmark model</i>	<i>Alternative specification</i>		<i>Benchmark model</i>	<i>Alternative specification</i>	
		<i>Model A</i>	<i>Model B</i>		<i>Model A</i>	<i>Model B</i>
<b>Economic growth equation</b>	Annual percentage growth rate of GDP per capita					
Change k	-0.022 (0.064)	-0.030 (0.064)	-0.032 (0.064)	0.042 (0.065)	0.038 (0.065)	0.039 (0.065)
Ht-1	-6.374 (6.974)	-6.600 (6.945)	-6.658 (6.937)	-5.913 (6.644)	-6.006 (6.624)	-6.014 (6.630)
Change H	<b>-24.136**</b> (12.416)	<b>-24.319**</b> (12.360)	<b>-24.644**</b> (12.351)	4.653 (11.743)	4.631 (11.706)	4.807 (11.720)
EINNOV	-0.016 (0.040)	-0.018 (0.040)	-0.019 (0.040)	<b>-0.141***</b> (0.039)	<b>-0.143***</b> (0.039)	<b>-0.142***</b> (0.039)
lnY0	2.520 (2.331)	2.573 (2.324)	2.582 (2.322)	3.236 (2.256)	3.259 (2.251)	3.265 (2.253)
TLF	-8.241 (9.446)	-7.053 (9.429)	-6.823 (9.421)	-14.639 (9.533)	-14.071 (9.503)	-14.123 (9.513)
Exp	-0.123 (0.096)	-0.119 (0.096)	-0.118 (0.096)	-0.127 (0.095)	-0.124 (0.095)	-0.125 (0.095)
Tax	-0.009 (0.081)	-0.010 (0.081)	-0.012 (0.081)	-0.0140 (0.082)	-0.015 (0.082)	-0.014 (0.082)
Balance	-0.064 (0.052)	-0.059 (0.052)	-0.058 (0.052)	-0.090 (0.055)	-0.087 (0.055)	-0.087 (0.055)
INF	-0.020 (0.017)	-0.021 (0.017)	-0.021 (0.017)	0.020 (0.017)	0.020 (0.017)	0.020 (0.017)
OPENG	0.012 (0.010)	0.013 (0.010)	0.012 (0.010)	0.009 (0.010)	0.009 (0.010)	0.009 (0.010)
<b>Physical investment equation</b>	Real gross fixed capital formation as a percentage of GDP					
ET	<b>-0.012***</b> (0.002)	<b>-0.012***</b> (0.002)	<b>-0.010***</b> (0.003)	<b>-0.010***</b> (0.002)	<b>-0.010***</b> (0.002)	<b>-0.011***</b> (0.003)
DEBT		<b>-0.029***</b> (0.010)	-0.018 (0.014)		<b>-0.025**</b> (0.010)	<b>-0.032**</b> (0.014)
ET#DEBT			-0.0001 (0.000)			0.00004 (0.000)
Exp	-0.049 (0.096)	-0.021 (0.097)	-0.022 (0.097)	-0.075 (0.101)	-0.056 (0.100)	-0.055 (0.100)
Tax	<b>-0.162**</b> (0.079)	-0.099 (0.082)	-0.091 (0.082)	-0.100 (0.082)	-0.047 (0.084)	-0.052 (0.085)
DCPS	-0.002 (0.004)	<b>-0.008*</b> (0.005)	<b>-0.009*</b> (0.005)	-0.006 (0.004)	<b>-0.011**</b> (0.005)	<b>-0.010**</b> (0.005)
RQ	1.039 (0.818)	0.773 (0.822)	0.704 (0.824)	-0.036 (0.829)	-0.226 (0.827)	-0.204 (0.828)
GNS	<b>0.343***</b> (0.043)	<b>0.305***</b> (0.045)	<b>0.305***</b> (0.045)	<b>0.314***</b> (0.046)	<b>0.282***</b> (0.047)	<b>0.282***</b> (0.047)
<b>Human capital equation</b>	Human-skill index					
LCO2	-0.009 (0.007)	-0.009 (0.007)	-0.009 (0.007)	0.001 (0.007)	0.001 (0.007)	0.001 (0.007)
exp	0.0003 (0.0005)	0.0003 (0.0005)	0.0003 (0.0005)	-0.0001 (0.0005)	-0.0001 (0.0005)	-0.0001 (0.0005)
FERT	-0.009 (0.006)	-0.009 (0.006)	-0.009 (0.006)	-0.008 (0.006)	-0.008 (0.006)	-0.008 (0.006)
TID	<b>0.093***</b> (0.028)	<b>0.093***</b> (0.028)	<b>0.093***</b> (0.028)	<b>0.062***</b> (0.028)	<b>0.062***</b> (0.028)	<b>0.062***</b> (0.028)
RQ	0.003 (0.005)	0.003 (0.005)	0.003 (0.005)	0.001 (0.005)	0.001 (0.005)	0.001 (0.005)

	<i>Lags=4</i>			<i>Lags=5</i>		
	<i>Benchmark model</i>	<i>Alternative specification</i>		<i>Benchmark model</i>	<i>Alternative specification</i>	
	<i>Model A</i>	<i>Model B</i>		<i>Model A</i>	<i>Model B</i>	
<b>CO2 equation</b>	Logarithm of carbon dioxide emissions					
ET	-0.0001 (0.000)	-0.0001 (0.000)	-0.0001 (0.000)	0.00001 (0.000)	0.00001 (0.000)	0.00001 (0.000)
Y	<b>0.00001***</b> (0.001)	<b>0.00001***</b> (0.001)	<b>0.00001***</b> (0.001)	<b>0.00001***</b> (0.001)	<b>0.00001***</b> (0.001)	<b>0.00001***</b> (0.001)
TFCPEP_sh	<b>0.007***</b> (0.001)	<b>0.007***</b> (0.001)	<b>0.007***</b> (0.001)	<b>0.005***</b> (0.001)	<b>0.005***</b> (0.001)	<b>0.005***</b> (0.001)
Lpop	<b>0.914***</b> (0.130)	<b>0.911***</b> (0.130)	<b>0.913***</b> (0.130)	<b>0.799***</b> (0.146)	<b>0.793***</b> (0.145)	<b>0.794***</b> (0.145)
OPENG	<b>0.0007**</b> (0.0003)	<b>0.0007**</b> (0.0003)	<b>0.0007**</b> (0.0003)	0.0005 (0.0003)	0.0005 (0.0003)	0.0005 (0.0003)
<b>Environmental innovation equation</b>	Development of environment-related technologies					
ET	<b>0.006**</b> (0.002)	<b>0.006**</b> (0.002)	<b>0.006**</b> (0.002)	<b>0.008***</b> (0.003)	<b>0.008***</b> (0.003)	<b>0.008***</b> (0.003)
ERGRDB	0.052 (0.103)	0.052 (0.103)	0.052 (0.103)	0.044 (0.101)	0.045 (0.101)	0.044 (0.101)
FDI	-0.029 (0.017)	-0.029 (0.017)	-0.029 (0.017)	0.003 (0.016)	0.003 (0.016)	0.003 (0.016)
TFCPEP_sh	-0.009 (0.060)	-0.009 (0.060)	-0.009 (0.060)	-0.007 (0.066)	-0.007 (0.066)	-0.007 (0.066)
RDPI	1.199 (1.121)	1.186 (1.122)	1.199 (1.121)	1.193 (1.129)	1.203 (1.129)	1.189 (1.128)
Observations	495	495	495	463	463	463
Number of countries	31	31	31	31	31	31

Note: \*, \*\*, and \*\*\* indicates the significance level at 10, 5, and 1% respectively based on the two-tailed test. Standard error estimates are in parentheses. The country-specific effect ( $\eta_i$ ), the time-specific effect ( $\lambda_t$ ), and the constant were included in the regressions of each equation in the model but they are not presented in this table.

*Table 3.5: Estimation results in the long term (number of lagged years equals to 4 and 5)*

### 3.8. Marginal effect of energy taxes on economic growth rate

The main findings of the previously presented estimations are that energy taxes seem to have a negative effect on physical investment and a positive impact on eco-innovation in the short and long term. In addition, these taxes can promote human skill through reducing the CO2 emissions in the short and long term. These results make us wonder about the marginal effect of energy taxes on economic growth rate. The marginal effect for imputed data is usually calculated by using “*mimrgns*” Stata command. But, the indirect relationship between energy taxes and economic growth rate makes this command does not work in this model. For this reason, the marginal effect of energy taxes on economic growth rate per capita was calculated

manually by using an Excel program. To know how economic growth rate varies when the proxy of energy taxes increases of one percent, three steps were followed. Firstly, the value of economic growth rate was calculated at the means of all explicative variables. Secondly, we calculated the value of economic growth rate at the mean of energy taxes plus 1% of energy taxes mean, and at the means of the other explicative variables. Finally, the variation between the value of economic growth rate in the second step and in the first step was calculated. The results are presented in the table (3.6). The findings reveal that an increase of 1% of the proxy of energy taxes leads to a decrease of economic growth rate per capita by 0,03386 in the short term. However, this negative impact decreases in long term and it becomes positive when the lagged value equal to three and five years.

	<b>Short term</b>	<b>Long term</b>				
		<b>Lag1</b>	<b>Lag2</b>	<b>Lag3</b>	<b>lag4</b>	<b>Lag5</b>
<b>Benchmark model</b>	-0,03373	-0,00007	-0,00009	0,00143	-0,00019	0,00311

*Source: author's calculation*

*Table 3.6: Marginal effect of energy taxes on economic growth rate per capita*

### **3.9. Conclusion**

This chapter investigated the effect of energy taxes on physical investment, human capital, and environmental innovation in the context of an endogenous growth model, where physical investment, human capital and environmental innovation represent the three mains channels through which energy taxes can affect economic growth. Moreover, it explored whether the impact of energy taxes on physical investment is sensitive to the existence and level of public debt-to-GDP ratio. The analysis was performed over the short and long term using a simultaneous-equations model with a panel of 31 OECD countries over the 1994–2013 period. The conditional mixed process (cmp) estimator developed by [Roodman \(2011\)](#) was used to estimate the model's coefficients. The multiple imputation method with an Expectation Maximization Bootstrapped algorithm was implemented to complete the missing data in our database. The main findings show a negative impact of energy taxes on physical investment in the short and long term. This impact is negatively sensitive to the existence and to the level of public debt. These results could be insightful for policymakers, especially for countries that are planning or implementing environmental tax reforms. Using of a part of



energy tax revenues to decrease the level of public debt could reduce the negative impact of public debt and of energy taxes on physical investment. In addition, we have found that energy taxes have an indirect effect on human capital through their impact on CO<sub>2</sub> emissions, as the taxes on energy products are able to reduce both flux and stock of CO<sub>2</sub> emissions that have a negative impact on human skill in the short and long term. Moreover, the empirical results show that energy taxes can encourage eco-innovation in the short and long term. However, environmental innovation promotes economic growth only after a period of two or three years. These empirical insights are of particular interest to policymakers as they help build sound economic and environmental policies to sustain economic development and to improve environmental quality.

## General Conclusion

Four and a half years ago, we have started our research work on this thesis, motivated by the importance of two key elements: *environmental tax and public debt vis-à-vis* of economic growth. Tax is one of the fiscal tools that has seen increasing use by the OECD countries as an instrument principal in their environmental policies over the last three decades. The main objective of environmental tax is to reduce pollution and greenhouse gas emissions, which increases the wellbeing of society. However, this can have a negative influence on economic growth, especially in the short term (Siriwardana et al., 2011; Wang et al., 2015). The use of this tool has sparked widespread debate among researchers about the impact of environmental tax on economic growth in the short and long term. This prompted them to use many theoretical models to answer this question, but without reaching a general consensus on the nature of this effect. Some of them found a positive impact whereas others observed a negative one.

Two points raised our attention on this subject. First, the empirical studies that verify the validity of these results are very rare. To the best of our knowledge, Abdullah and Morley (2014) is the only published econometric study on this topic. Second, the majority of the theoretical models applied to studying the effect of environmental tax on economic growth ignore the public debt issue. They assume that the government finances its expenditures only through taxes and that the government budget is balanced in every period. But in fact, the high ratios of public debt-to-GDP, caused by the last financial crisis, have been one of the features of advanced economies in recent years. Many studies showed that, high levels of public debt can lead fiscal policy to adversely affect economic growth; while low levels allow fiscal policy to promote economic progress (Baharumshah et al, 2017; Bhattarai et al., 2014; Chen et al. 2016; Gogas et al., 2014; Galstyan and Velic, 2017; Gwartney, 1998 ;Teles and Cesar Mussolini, 2014a). Therefore, as the environmental tax is a fiscal instrument used by environmental policy, its effect on economic growth could be sensitive to the existence and level of public debt.

Thus, our main goal in this thesis was to explore the nature of the relationship between environmental tax and economic growth, and whether this relationship is sensitive to the level of other variables in the economy. Then, in second place, we aimed to examine the channels

through which this tax can affect economic growth, and whether the existence and level of public debt could alter this effect.

In order to achieve the thesis' goals, we started a long research path by firstly determining the main drivers of economic growth according to the empirical and theoretical literature, in particular the endogenous growth models. Four groups of control variables were determined in this phase: the conditioning variables of economic growth; the variables of fiscal policy; human capital variables, and macroeconomic variables. Then, a proxy of environmental tax was added to these indicators. In the first chapter, this proxy measured the total revenues of all environmentally related taxes as a percentage of GDP, while in the second and the third chapters we focused our analysis on the most important category of environmentally related taxes: energy taxes. Therefore, we built a new proxy for energy taxes which takes into account changes in its tax base.

In the second phase, we reviewed the literature examining the effect of environmental tax on economic growth, which allowed us to identify three main channels through which this tax could influence economic growth. They are: physical capital, human capital and environmental innovation. For each of them, we determined a set of explanatory variables used in the existing literature.

Afterwards, we proceeded to the collection of data on the chosen indicators that will be later submitted to different estimation approaches. At this stage, we had a concern about the *missing data*, which is recognized to have serious consequences on results validity. To address this problem, the *multiple imputation* method developed by the seminal work of (Rubin 1976) was used, giving our inferences further validity; compared to those resulting by using missing values. However, if the variable has zero observation, this method cannot create its missing data by using the observed value of other variables in the database. For this reason, we were obliged to exclude Chile, Mexico and United States from our database, because they have no data about productive expenditure variable. Therefore, we constructed a balanced panel dataset of 31 OECD countries for the period 1994-2013. In addition, information about the implementation of *environmental tax reforms* was collected by using a literature review. After that, two approaches were employed to estimate the parameters of models in this thesis. In the first and second chapter, we used the *Correlated Random Effects* estimator developed by Wooldridge (2010). This method is able to address the problem of endogeneity caused by

the correlation between model variables and unobserved effects of time-invariant variables (Bache et al., 2013). In the third chapter, the conditional mixed process (cmp) estimator developed by Roodman (2011) was used in order to estimate the simultaneous-equations model's coefficients. Instrumental variables were employed with this estimator to treat the endogeneity issue which may arise due to simultaneity. For both approaches, we verified that there is no harmful multi-collinearity between the explanatory variables by using the *Variance Inflation Factor* test, and that the time series of environmental tax proxy and economic growth rate are stationary, by using a group of panel root tests.

Consequently, four and a half years' efforts have resulted in three empirical chapters. Table (A.1) presents briefly the main contributions to this thesis which are of empirical nature:

Chapter	Contribution
Global contributions	<ul style="list-style-type: none"> <li>- This thesis represents the motivation of a new theoretical model that takes into account the three channels through which environmental tax can affect economic growth, in addition to the existence of the public debt.</li> <li>- It handles the problem of missing data by using the multiple imputation method which showed an improvement in data quality and statistical inference.</li> </ul>
Chapter 1	<p>The empirical contribution of this chapter lies in three aspects:</p> <ul style="list-style-type: none"> <li>(i) Exploring the nature of the relationship between the overall environmentally related tax revenues and the economic growth rate in the short and long term.</li> <li>(ii) Investigating whether this relationship is sensitive to the level of revenue generated from environmentally related taxes or to the initial level of a country's richness.</li> <li>(iii) Examining whether this relationship differs between the countries which have implemented ETRs and those which have not?</li> </ul>
Chapter 2	<p>This chapter proposes a new approach to measure energy taxes. This approach takes into account not only the revenue generated from these taxes but also the changes in its tax base. After that, the new</p>

	<p>proxy of energy taxes was used to achieve two goals:</p> <ul style="list-style-type: none"> <li>(i) Exploring the nature of the relationship between energy taxes and economic growth rate in the short and long term.</li> <li>(ii) Verifying whether this relationship depends on the initial level of a country's richness, polluting energy use (as internal factors in the economy) and commercial openness of goods (as an external factor in the economy).</li> </ul>
Chapter 3	<p>Two novelties are provided by this chapter:</p> <ul style="list-style-type: none"> <li>(i) It is the first attempt to empirically examine the channels through which energy taxes can affect economic growth rate in the short and long term, by using a simultaneous equations model.</li> <li>(ii) It is the first macro-econometric evidence on the sensitivity of the effects of energy taxes on physical investment and thus on economic growth for the existence and level of public debt.</li> </ul>

*Table A.1: Thesis contributions*

In Chapter 1, the share of total environmentally related tax revenues in GDP was used as a proxy of environmental tax. In the first phase, our interest was to investigate whether there is a relationship between this proxy and the economic growth rate in the short and the long term. The answer to this question shows whether the use of tax as an instrument for environmental policy has any correlation with economic growth, and whether it will have a positive or negative association. In the second phase, the significant rise in the revenues generated from these taxes in the OECD zone, which have increased from 420.754 billions US\$ in 1994 to 786.134 billion US\$ in 2013, led us to wonder whether this relationship is sensitive to the level of revenues generated. On the other side, we wanted to explore whether the nature of the relationship between environmental tax and the economic growth rate is sensitive to the initial level of a country's richness. The former has been measured by the natural logarithm of GDP per capita in the year 1994. It was coded as  $(\ln Y_0)$ . To achieve these goals, we allowed the proxy of environmental tax to interact with itself and with  $(\ln Y_0)$ . Finally, motivated by the wave of environmental tax reforms that started in the early 1990s in a number of OECD countries; we investigated whether the nature of the relationship between environmental tax

and the economic growth rate differs between the countries that have implemented these reforms and those that have not implemented them.

Using the Correlated Random Effects (CRE) panel data estimator, we found that there is no statistically significant relationship between the overall share of environmentally related tax revenues in GDP and economic growth rate in the short and long term. However, when we allowed ETRT to interact with  $\ln Y_0$ , this relationship became significant and negative, reflecting the importance of a country's richness level in determining the nature of this relationship. Furthermore, we found that, the higher the initial level of GDP per capita, the more environmentally related tax revenues can promote the economic growth rate. The coefficient of the interaction between the total revenue of environmentally related taxes and itself did not show a significant effect. The results also revealed that the association between environmentally related tax revenues and the economic growth rate, in the short and long term, is statistically insignificant in the countries which have not implemented ETRs, whereas this association is statistically significant and negative in the countries which have implemented ETRs.

In Chapter 2, we have focused our analysis on energy taxes which represent the most important category of environmentally related taxes in terms of the number of taxes imposed and the revenues achieved. This allowed us to propose a new approach to measure these taxes. In fact, the insignificant relationship between total environmental tax revenues and the rate of economic growth, which we obtained in the first chapter when the interaction with other variables was ignored, made us question how well the units used to measure these revenues could show the real impact of these taxes on economic growth. According to the statistics provided by the OECD, there is only a data about the revenue generated from environmentally related taxes. These revenues are measured in four unites: millions of USD, a share of total tax revenues, per capita, and a percent of GDP. However, we noticed that these measurements do not take into account the changes in the tax base. This may weaken the role that environmental taxation can play in the economy and does not reflect its real impact on the economic variables. Consequently, in this chapter, we proposed an alternative approach taking into account, not only the revenue generated, but also the variations in the tax base. The total final consumption of energy products that pollute the environment through carbon emissions was considered as a proxy of energy taxes' base. Then, the new proxy of energy taxes was calculated through dividing energy tax revenues measured in millions of American

dollars by the total final consumption of polluting energy products measured in tons of oil equivalent. After that, this new measurement was used to explore the nature of the relationship between energy taxes and the economic growth rate in the short and long term. In addition, we compared our estimations results from this proxy to those obtained from the other measurements of energy taxes provided by the OECD statistics. Finally, this proxy was employed to test whether this relationship is sensitive to the initial level of a country's richness, polluting energy use and commercial openness of goods.

The estimation results of the Correlated Random Effects estimator revealed a negative relationship between the new proxy of energy taxes and economic growth rate in the short term, whereas the four units provided by the OECD statistics to measure energy taxes did not show any significant association. When we allowed this proxy to interact with the other variables, energy taxes negatively correlated with the economic growth rate in the short and the long term. This association is negatively sensitive to the level of the economy's dependence on polluting energy use as a share of total energy used in the production process in the short and long term, and to the commercial trade openness only in the long run. In addition, the results show that an increase in energy taxes can significantly enhance the economic growth rate, as the initial level of a country's richness increases. To know the net effect of these taxes on the economic growth rate, we calculated the average marginal effect. We found that the average marginal effect of these taxes on economic growth is negative in the short term. However, this negative impact decreases in the long term and it becomes positive after three years.

Motivated by the results of chapter 2, we empirically investigated in chapter 3 the channels through which energy taxes could influence economic growth rate in the short and long term. The theoretical literature of environmental economics supposes that imposing taxation on energy products can affect economic growth through three main channels: physical capital (physical investment); human capital; and environmental innovation. The impact of these taxes on physical investment is expected to be direct and negative, whereas the effect on human capital is supposed to be positive and indirect, through its impact on pollution emissions. The authors also assume that these taxes can promote economic growth through encouraging environmental innovation. However, all these assumptions are theoretical and to date there is no empirical evidence that examines the validity of these hypotheses together in the same model. Therefore, this chapter complements this shortage of empirical studies. In

addition, the majority of the theoretical models applied for studying the effect of environmental taxation on economic growth ignored the public debt issue by supposing that the government budget is balanced in each period, whereas the high level of public debt-to-gross domestic product ratio is one of the features of advanced economies in recent years. This was our motivation to include the public debt in our analysis in this chapter. More precisely, we firstly determined the main channel through which public debt can affect economic growth by reviewing theoretical and empirical literatures. We found that this channel is the physical investment. We examined then whether the effect of energy taxes on physical investment is sensitive to the existence and level of public debt.

The analysis was performed in the short and long term by using simultaneous-equations model in case of 31 OECD countries over the 1994–2013 period. The conditional mixed process (cmp) estimator developed by [Roodman \(2011\)](#) was used to estimate the model's coefficients. The endogeneity problem that can occur in this model because of simultaneity was treated by using instrumental variables. In consistent with the expectation, estimation results showed four mains results. First, there is a negative effect of energy taxes on physical investment in the short and long term. This effect appeared to be negatively sensitive to the presence and to the level of public debt. In other words, the higher the level of a country's public debt, the more the negative impact of energy taxes on physical investment increases. Second, we found that there is an indirect and positive effect of energy taxes on human capital through its impact on pollution where, the taxes on energy products are able to reduce the polluting emissions, which have a negative impact on human skill in the short and long term. Third, the results showed that energy taxes can encourage environmental innovation in the short and long term. However, environmental innovation promotes economic growth only after a period of two or three years.

## **A.1. Policy implications**

The findings generated by these works point to many implications for policymakers. **Firstly**, the questions of fairness and the inequitable effects of environmental policies on the poor countries were primary concerns for policymakers during the negotiations of the Paris Agreement (2015). This thesis showed that the effect of environmentally-related taxes, in general, and energy taxes, in particular, on the economic growth rate is positively sensitive to the initial level of a country's richness. This means that introducing these taxes in countries having a low level of initial GDP per capita (poor countries) will damage the economic



growth rate, while these taxes could promote the economic growth rate when the initial level of GDP per capita is high (rich countries). Consequently, this finding validates the argument made by developing countries that using the tax as an instrument of environmental policy may constitute a barrier to economic growth of which they are just beginning to reap its benefits. In this case, rich countries can provide financial and technological assistance to developing countries to help them reduce the negative effects of these taxes on their economies. **Secondly**, chapter 2 found that the effect of energy taxes on the economic growth rate is negatively sensitive to the level of a country's fossil fuel consumption, in the short and the long term, and to the level of country's trade openness of goods, only in the long term. Based on these results, we suggest that governments having introduced energy taxes or planning to increase these taxes in order to reduce polluting emissions, should, at the same time, work to encourage the shift toward clean energy use and to increase the efficacy of polluting energy use, because this could reduce the consumption of fossil fuel and thus reduce the negative effect of energy taxes on economic growth. Additionally, the government should provide support to industrial enterprises that direct their production for export, in order to compensate for part of the increase in costs resulting from energy taxes. This may improve their competitiveness in the global markets and thus increase their exports. However, we suggest that the government's subsidy to the affected industrial sectors should not be in the form of lump-sum payments, as this could eliminate the effect of costs increases resulting from energy taxes, thus canceling the economic motivation to switch to clean energy or invest in environmentally friendly technology. Therefore, the consumption of polluting energy will not decrease. Instead, the government can provide support in the form of direct funding for research projects provided by industrial enterprises to invest in environmentally friendly technology or in clean energy use. On the other side, this chapter showed that the method used to measure energy taxes is an important issue and it can change the implications of public policy. Consequently, we propose to build a new measure of environmentally-related tax categories that takes into account the variation in their bases. **Thirdly**, the findings obtained by the third chapter help policymakers to answer the question: what should be done to reduce polluting emissions at minimum economic cost? Through the empirical study, we found that energy taxes have a negative impact on CO<sub>2</sub> emission in the short and long term. Thus, in order to reduce the emissions of carbon dioxide, governments of developed countries can expand energy taxes use, either by increasing their rates, or expanding their tax base. But this will have negative effects on some engines of economic growth (physical investment) and positive effects on others (human capital and environmental innovation). Consequently, in

order to reduce the negative effects of these taxes on economic growth, the expansion of their use must be accompanied by supporting for the channels that are negatively impacted by these taxes and by promoting the channels that are positively affected. This can be achieved through an energy tax reform based on the use of its revenues as follows:

1. A part of the revenues could be used to reduce the public debt, especially in countries with a high public debt to GDP ratio. This could first reduce the negative impact of public debt on physical investment, and secondly reduce the negative impact of energy taxes on physical investment, as energy taxes are negatively sensitive to the existence and level of public debt.
2. The government could use a part of the revenue to increase the expenditure on physical investment in the education sector (building schools and universities).
3. A part of the revenues could be used to increase the environmentally related government R&D budget as a percentage of total government R&D (ERGRDB), which shows a positive impact on environmental innovation when the explanatory variables are lagged for two years.

In addition, increasing the R & D personnel intensity by recruiting more researchers can promote environmental innovation.

## **A.2. Limitations and future perspectives**

During the preparation of this thesis we have faced some limitations that mainly concern data collecting. The data was restrained to include only 31 OECD countries, because of completely missing patterns of data that concern productive expenditure variables for Chile, Mexico and USA. Additionally, Latvia, which recently joined to the OECD, has no data on environmentally related tax revenues. Therefore, it was excluded from the sample. The selection of the period of study, which was from 1994 to 2013, was constrained by the availability of data about environmentally related tax revenues that have been newly introduced in most OECD countries, and about human capital variable. The environmentally related tax revenue data provided by the OECD statistics cover the period 1994-2014. But as the data on capital human is available only until 2013, we decided to restrict our study to the period from 1994 to 2013. As a result, our sample was built to contain only (31) countries' members in the OECD over the 1994-2013 period.

At the end of this thesis in which many technical tools and concepts have been used, we can see through it the start of further future works. From a theoretical point of view, the empirical

results obtained in this work can serve as an incentive to develop a theoretical model which takes into account the three channels through which energy taxes can affect the economic growth rate, in addition to the existence of the public debt at the same time. From an empirical perspective, the **first proposition** could be an extension of Chapter 1, where we investigated whether the relationship between environmentally related tax revenues and economic growth rate varies between the countries that implemented ETRs and those that did not. However, we did not estimate the impact of ETRs on the economic growth rate. This question could be a project for a future work. **The second one** is inspired from Chapter 2, where we explored the nature of the relationship between energy taxes and the economic growth rate. As we found a significant relationship, without interacting energy taxes with other variables, this creates a motivation to explore the ‘*causal relationship*’ between them. **Finally**, the questions proposed by this thesis could be re-examined in the future by using: (i) a longer time series, which allows employing other models like time series estimators or dynamic models, (ii) a new database for the countries non-members in the OECD.

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# Appendices

# Chapter 1 Appendix

## Appendix 1.A: Brief of variables and source of data

Code	Description	Data source
	<i>Dependent variable</i>	
gr	Annual percentage growth rate of GDP per capita	(WDIs, 2015)
	<i>Environmental taxes</i>	
ETRT	The total revenues of all environmentally related taxes as a percent of GDP	(OCDE, 2015)
	<i>Conditioning variables</i>	
Lny0	The natural logarithm of initial value of the real GDP per capita for each country in the year 1994 <sup>27</sup> .	(WDIs, 2015)
k	Real gross fixed capital formation (% of GDP) (a proxy of physical capital) <sup>28</sup> .	(WDIs, 2015)
Change k	Annual change of physical capital. it is defined as $(k_t - k_{t-1})$ .	Author according to data from (WDIs, 2015)
TLF	Total labor force growth rate.	(WDIs, 2015)
	<i>Human capital</i>	
H	Human capital stock. The human-skill index is used as a proxy of human capital.	(LEAD, 2015)
$H_{t-1}$	The level of human capital in the previous year.	Author according to data from (LEAD, 2015)
Change H	Annual change in human capital.	Author according to data from (LEAD, 2015)
	<i>Fiscal policy</i>	
exp	Productive expenditure, defined as the sum of general government spending on education, health, housing, public order and safety, and defense as a percentage of GDP.	(OECD and GFS, 2015)

<sup>27</sup> The gross domestic product is measured at constant 2005 U.S. dollars and purchasing power parity (PPP).

<sup>28</sup> Gross fixed capital formation is measured in constant 2005 U.S. dollars.



<b>Code</b>	<b>Description</b>	<b>Data source</b>
tax	Distortionary taxation. It is the sum of taxes imposed on income, profit and capital gains, payroll and workforce, as well as social security contributions as a percentage of GDP.	(OECD, 2015)
Balance	Fiscal balance (surplus/deficit) as a percent of GDP.	(OECD, 2015)
	<i>Macro control variables</i>	
INF	Inflation rate is measured by the annual percentage change in the Consumer Price Index.	(WDIs, 2015)
OPENG	Openness to international trade of goods is calculated as (exports plus imports of goods) as percentage of GDP.	(OCDE, 2015)

*Source:* World Development Indicators (WDIs), World Governance Indicators (WGIs), Organization for Economic Cooperation and Development (OECD), Government Finance Statistics (GFS), “Laboratoire d’Économie Appliquée au Développement (LEAD)” in Toulon University (France).

*Table 1.A: Brief of variables and source of data*

## Appendix (1.B)

### Missing Data & How to Deal

The issue of incomplete data sets is a common obstacle in the world of empirical economic studies. It prevents scientists from obtaining unbiased results in their research. Many methods are proposed to deal this problem. In this section, we provide a brief survey of missing data solutions.

1. *Listwise* and *pairwise* deletion are common techniques used by most statistical packages to handle missing data (Peugh and Enders, 2004; Honaker et al., 2011). Listwise deletion (complete-case analysis) excludes all data for a case that has one or more missing value. Consequently, the number of observations used in the analysis declines. This can cause biased estimates, leading to invalid conclusions (Kang, 2013). Pairwise deletion only removes the specific missing values from the analysis (not the entire case). That is, all available data is included to produce estimates of mean, correlations and covariance. Nevertheless, there are many problems of this method. When a correlation on multiple variables is conducted, pairwise deletion will conduct the bivariate correlation between all available data points, and ignore only those missing values if they exist on some variables. In this case, pairwise deletion will result in different sample sizes for each correlation, which can generate correlations outside the range  $[-1,+1]$ . In addition, it is not clear which sample size should be used for calculating standard errors. Using the average sample size yields standard errors that are too small (Little, 1992).

2. Estimation the missing values and then using the new values is another solution to handle missing data. There are different methods to do the estimation: *mean imputation*; *using regression*; *stochastic regression imputation*; *Last Observation Carried Forward (LOCF)* and *Baseline Observation Carried Forward (BOCF)*; and *indicator method*. More details about these methods are provided by (Buuren 2012). The standard calculations of these methods make no distinction between the observed data and the imputed data. This makes the standard errors after imputation ‘too small’ (Buuren, 2012). *Multiple imputation* (MI) method can solve the problem of ‘too small’ standard errors. In addition, it separates the solution of the missing data problem from the solution of the complete data problem. It solves first the missing data problem, then the complete data problem. Buuren (2012) states that multiple imputation method is the best solution given all other imputation methods disadvantages.

## The alternative approach to handle missing data: multiple imputation

Since the seminal work of Rubin (1976), *multiple imputation* (MI) has become the most popular method for dealing with missing data in last three decades. The multiple imputation technique consists of three main steps: imputation, analysis and pooling. In the first step, multiple imputation imputes  $m$  values<sup>29</sup> for each missing observation using the Expectation-Maximization with Bootstrapping (EMB) algorithm, which generates estimates of missing data using the observed ones. It then fills every missing cell with imputed values, creating  $m$  “completed” data sets. In the second step, multiple imputation analyzes each of the  $m$  completed data sets, resulting in  $m$  analyses. In the last step, the  $m$  analysis results are integrated into a final result using Rubin’s (1987) original formula that combines variability within and between data sets (for more details, see Honaker and King, 2010 and Honaker et al., 2011).

To complete missing values in our data, we used a multiple imputation approach proposed by the *Amelia II* package available in R program (Honaker et al., 2011). The *Amelia II* package implements an expectation-maximization with bootstrapping (EMB) algorithm for large numbers of variables. The database employed for imputation purpose includes all the variables that we used in this thesis. It means, in addition to the variables used in chapter 1, we add the variables that will be used in the analysis models in chapter 2 and chapter 3. This procedure is recommended by (Honaker et al., 2011), because it adds more information to imputation model and thus increases its predictive power. Consequently, the proxy of energy taxes (ET), total final consumption share of polluting energy products in total final consumption of energy (TFCPEP\_sh), environmental innovation (EINNOV), domestic credit accorded to private sector (DCPS), regulatory quality (RQ), carbon dioxide emissions (CO2), total fertility rate (FERT), Technology Infrastructure Development (TID), GDP per capita (Y), population (POP), environmentally related government R&D budget as a percent of total government R&D (ERGRDB), foreign direct investment (FDI), R & D personnel intensity (RDPI) and public debt (DEBT) were added to imputation model. The explanation of these variables exist in chapter 2 and 3.

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<sup>29</sup> Where  $m > 1$  is the number of imputations.

Before starting the multiple imputation procedure, we wanted to get a good idea of the type and pattern of missingness in our data. The fraction of missing data is the tool used for this purpose. Table (1.B.1) presents this fraction for each variable<sup>30</sup>.

Variables	Fraction missing	Variables	Fraction missing
RQ	0.25	k	0.003
RDPI	0.18	TLF	0.00
exp	0.16	lnY0	0.00
ERGRDB	0.14	INF	0.00
Balance	0.08	TFCPEP_sh	0.00
DCPS	0.04	ETRT	0.00
DEBT	0.03	Y	0.00
FDI	0.03	FERT	0.00
EINNOV	0.01	CO2	0.00
OPENG	0.009	POP	0.00
ET	0.008	TID	0.00
tax	0.006	H	0.00
gr	0.006		

*Source: The author's calculation, according to the Amelia View results.*  
**Table 1.B.1: The fraction of missing data in decreasing order**

We can immediately see that: (i) the data of (H, TID, POP, CO2, ETRT, Y, ETRT, TFCPEP\_sh, INF, lnY0, TLF) variables are always observed; (ii) a few of values are missing for the variables (*gr*, *tax*, *ET*, *OPENG*, *EINNOV*, *FDI*, *DEBT*, *DCPS*, and *Balance*); and (iii) (*ERGRDB*, *exp*, *RDPI*, *RQ*) are the variables with the highest level of missingness in the data set. This is the reason why we focused our analysis on these four variables. After exploring the pattern of missingness in the data, we started the multiple imputation procedure. Identification of the variables that were to be included in the imputation model was the first step. According to [Honaker et al. \(2011\)](#), it is not appropriate to include country names and years variables in the imputation model. Therefore, we added the transformation of ID for the country and year variables (see [Honaker and King, 2010](#)). We then set  $m = 100$  and executed the multiple imputation process<sup>31</sup>. In order to verify imputation validity and the fitness of the

<sup>30</sup> It is calculated as “the number of missing observations in the variable across all countries”/ “the total number of data set lines”. The total number of data set lines is equal to number of countries multiplied by number of years in the sample.

<sup>31</sup> Concerning the question of how many imputations are required to get good results, it is always better to use a high value of  $m$  because it leads to higher statistical power ([Graham et al., 2007](#)) and less standard error in the multiple imputation point estimate ([Honaker et al., 2011](#)). However, we followed the recommendation of [Buuren \(2012, p.50\)](#) on the number of imputations, by starting the imputation with  $m = 5$ , then increasing it to

imputation model, we used two diagnostic tests available with the *Amelia II* package: *Comparing Densities*, and *Over-imputation*. As already mentioned, our focus was on the variables that own the largest fraction of missingness. These are: *RQ*, *RDPI*, *exp* and *ERGRDB*.

### ***Comparing Densities***

One of the methods for assessing the plausibility of imputations is to compare the distribution of imputed values with the distribution of observed values. The idea is that high quality imputed values will have a distribution similar to the observed value. Figure (1.B.1) shows kernel density estimates of the observed values and of the *mean* of imputed values over the *m* datasets. For each variable, the distribution of mean imputations is (in red) and the distribution of observed values is (in black). We see that imputed values of *RDPI* and *ERGRDB* are slightly similar to observed *RDPI* and *ERGRDB* values, but the imputations of *RQ* and *exp* are different from their observed values. This meant that the imputation model required some improvements.

### ***Over-imputation***

Over- imputation is the second tool used to check the plausibility of the imputation model. The idea of this method was to apply our imputation procedure to data that was not missing. Consequently, for each observed value, several hundreds of imputed values were generated. “This large number of imputations allows us to construct a confidence interval of what the imputed value would have been, had any of the observed data been missing. We can then graphically inspect whether our observed data tends to fall within the region where it would have been imputed had it been missing” (Honaker *et al*, 2011: 28). Figure (1.B.2) shows our over-imputation diagnostic for the four selected variables. On these graphs, the black line refers to the line of perfect agreement; which implies that, if the imputation model was a perfect predictor of the true value, all the imputations would fall on this line. The vertical lines show the 90% confidence intervals for imputed values. The colors of the lines indicate

---

20, 40 and to 100. The diagnostics of over-imputation were almost identical with *m* = 5, 20, 40 and 100, for the four variables that had the largest missing data fraction. Consequently, we decided to complete the treatment with *m* = 100 for the reasons mentioned above. (See appendix (1.C) which shows a comparison of over-imputation diagnostics).

the fraction of missing observations in the pattern of missingness for that observation (with red being a higher fraction and blue being a lower fraction). By looking at how many of the.

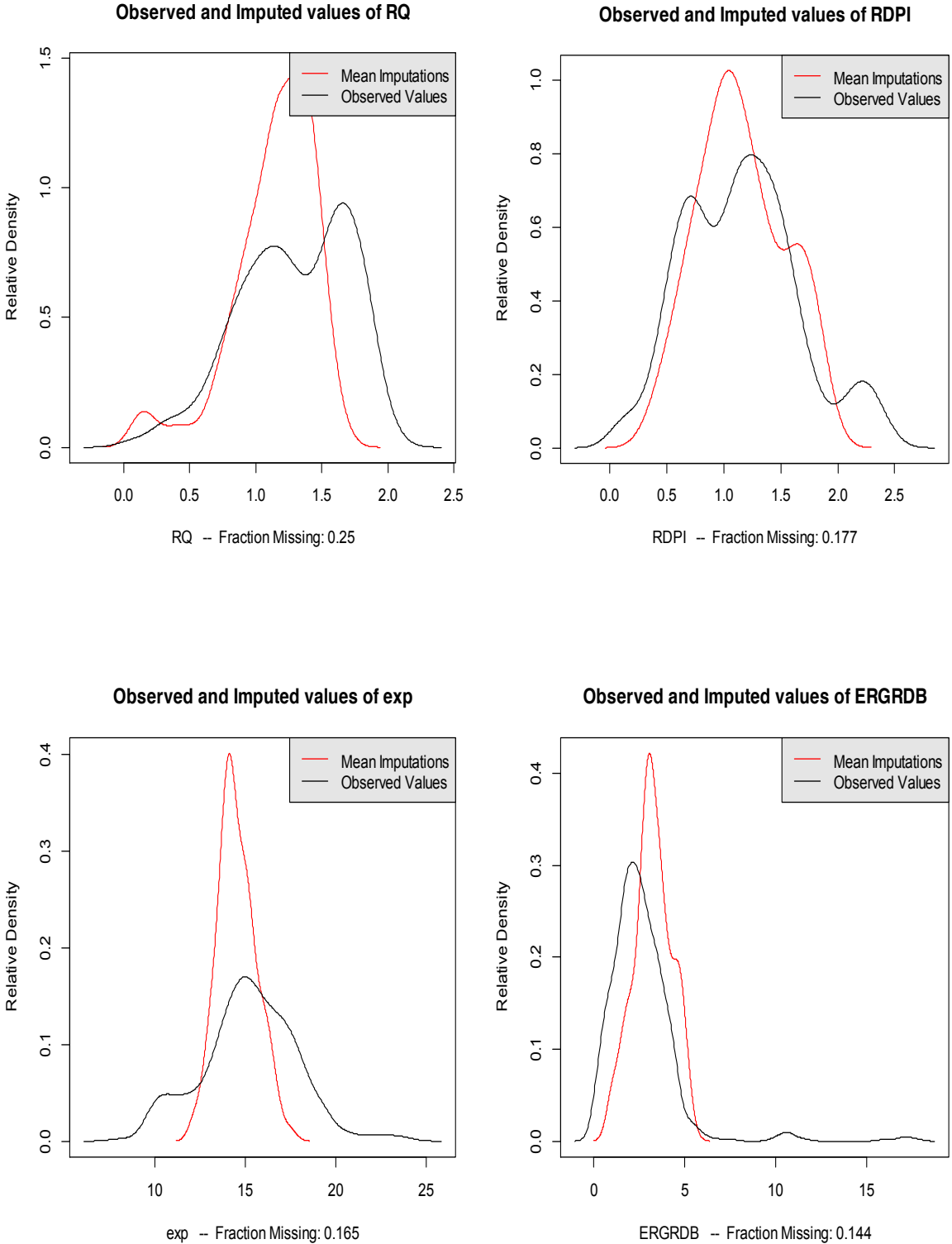
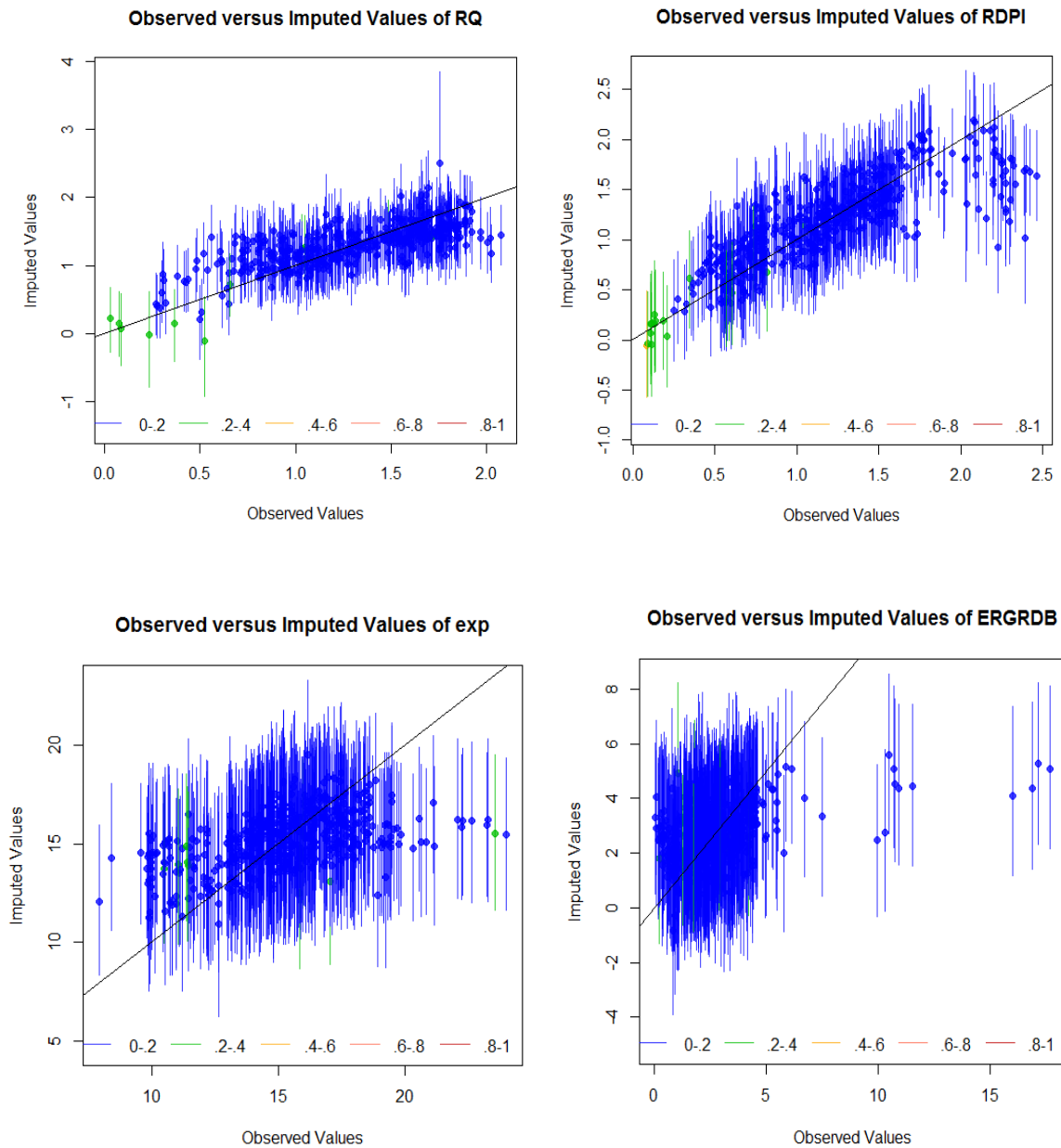


Figure 1.B.1: Comparing Densities, the distribution of relative density of the observed values (in black) and the distribution of relative density of mean imputations (in red) for each variable.



*Figure 1.B.2: Over-imputation diagnostic. The dots represent the mean imputation. The color of the line (as coded in the legend) represents the fraction of missing observations.*

confidence intervals cover the black line, we can tell how often the imputation model can confidently predict the true value of the observation. From the four graphs, we can observe that the majority of confidence intervals fall on the black line, which means the true observed value falls within this range. However, there are some confidence intervals that do not fall on this line. We can observe them on both sides of every square. Taking this into consideration

along with the results of the density diagnostic for the (*RQ*) and (*exp*) variables in the previous section, it was clear that the imputation model needed to be improved

## Imputation model improvement

As our data is panel, many variables can vary smoothly over time and/or *within* cross-sectional units. In this case, when the known values are close in time to a missing value, this may aid the imputation of that value enormously. However, there may be periods of decline, stability, or growth for which the observed values would be used in a different way to impute missing values. Consequently, the exact pattern may vary over time within any cross-section or may exist in some and not in others. Thanks to Amelia a general model of patterns within variables across time could be built by creating a sequence of polynomials of the time index. For example, if the economic growth rate (*gr*) varies smoothly over time, the modeling assumption supposes that there are some polynomials that describe the economy in cross-sectional unit (*i*) at time (*t*) as:

$$gr_{ti} = \alpha_0 + \alpha_1 t + \alpha_2 t^2 + \alpha_3 t^3 \dots$$

By including enough higher order terms of time, the pattern between observed values of the economic growth rate can be estimated. Amelia creates polynomials of time up to the user defined *k*-th order ( $k \leq 3$ ). In this way, the covariates that correspond to time and its polynomials are added to the model by Amelia. On the other hand, these polynomials can interact with the cross-section unit to allow the patterns to vary between cross-sectional units over time, when cross-sectional units are specified. There is also a probability that all units have the same patterns over time in all variables. In this case, *k* will take the value of zero. That means every unit has a uniquely estimated constant term (Honaker *et al.*, 2011). Consequently, there were three types of information that could improve the quality of imputation: The first being a sequence of polynomials of the time index, where  $k = 1$  or  $2$  or  $3$ ; the second an interaction between the sequences of polynomials of the time index and the cross-section unit; and the third an interaction between the cross-section unit and the polynomials of the time index, but with  $k = 0$ . We tested these cases using the Amelia program. We found that the best result was when we used ( $k = 0$ ) and interaction with the cross section, which is equivalent to using *fixed effects*, where every unit has a uniquely estimated constant term. Figure (1.B.3) shows the density comparing diagnostic



when we used a fixed effect (the best result of the three tests). Compared to the density comparing diagnostic performed before the improvement made to the of imputation model, presented in figure (1.B.1), we can see that the imputed curve for the four variables, has

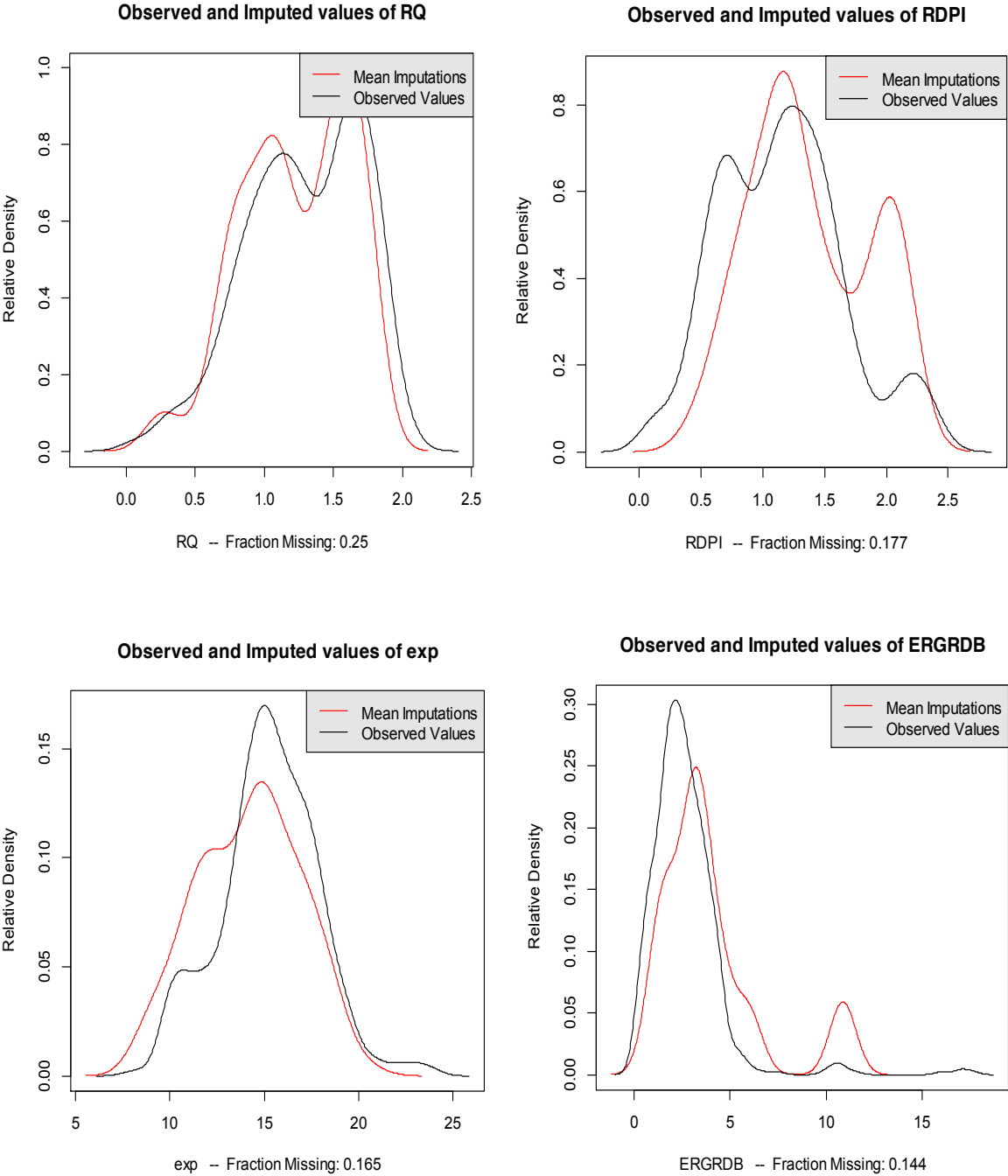
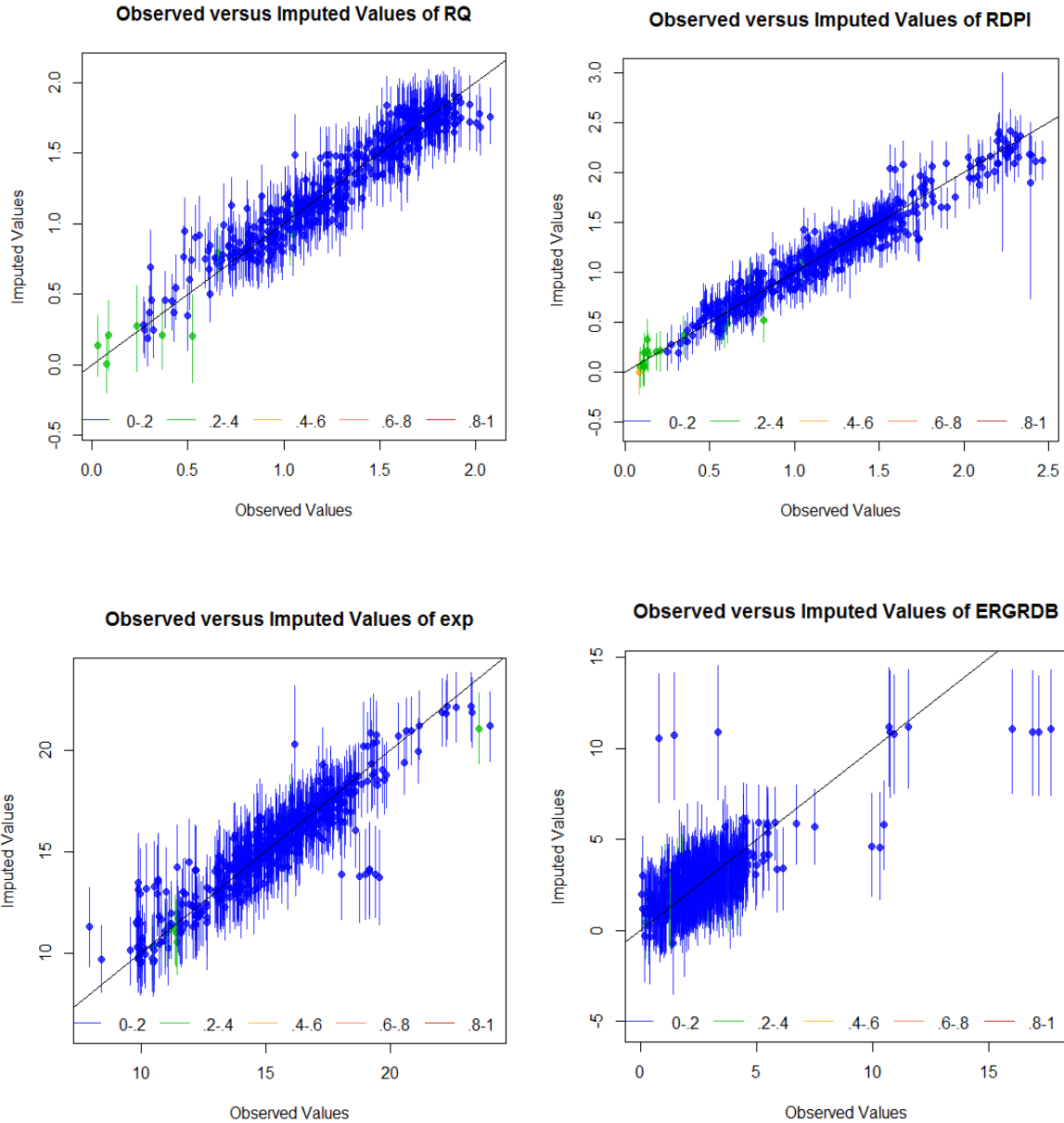


Figure 1.B.3: Comparing Densities, with  $k = 0$ , and interaction with the cross section



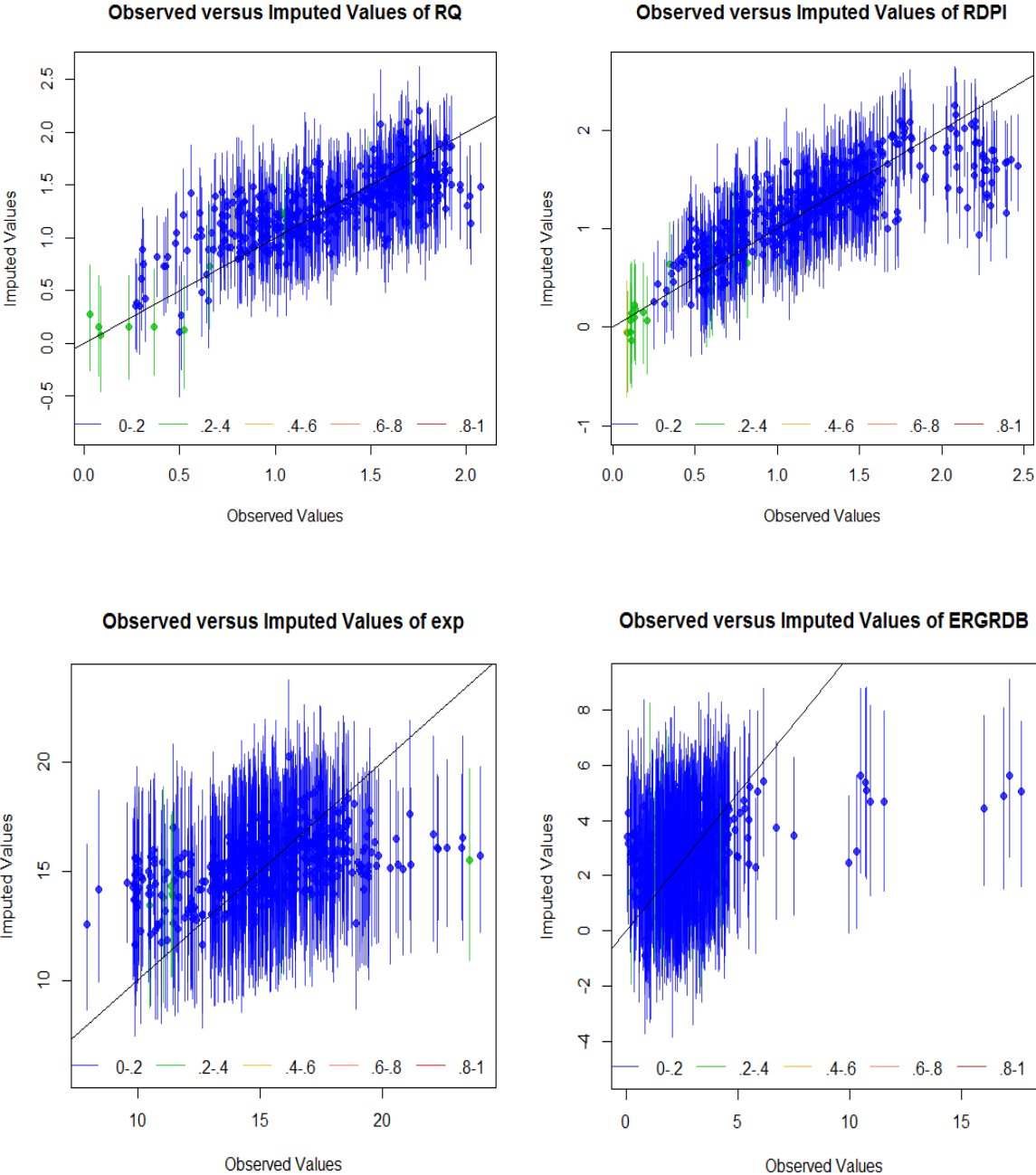
*Figure 1.B.4: Over-imputation diagnostics, with  $k = 0$ , and interaction with the cross section.*

improved. There is remarkable convergence between the relative intensity distribution curves of observed and imputed mean' values. This reflects a significant improvement in the imputation. This improvement is probably due to large number of countries that have the same pattern of missingness especially for the *RQ* variable. As a result, when we used the interaction with cross-section units, a lot of information was added to the imputation model. Over-imputation diagnostics presented in figure (1.B.4) also show that compared to figure (1.B.2), there is an improvement in the number of confidence intervals that cover the black line for the four variables. This reflects the plausibility and the fitness of the imputation model

with  $m = 100$ ,  $k = 0$  and interaction with the cross section. Consequently, we used the multiple imputation with these options to impute the missing values in our dataset.

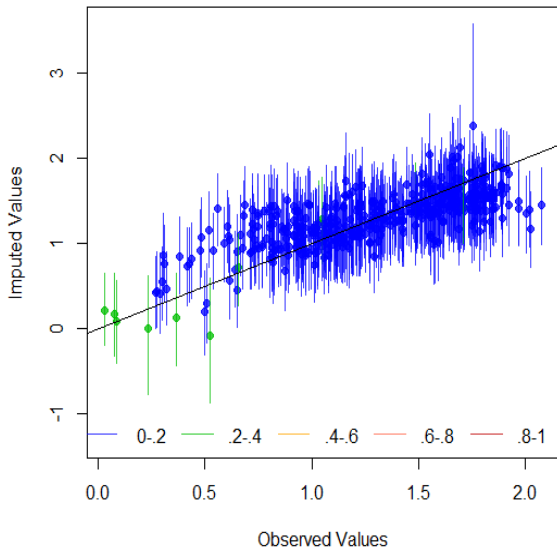
# Appendix (1.C)

Over-imputation diagnostics for *(RQ)*, *(RDPI)*, *(exp)*, and *(ERGRDB)* variables for  $m = 5, 20, 40, 100$  respectively.

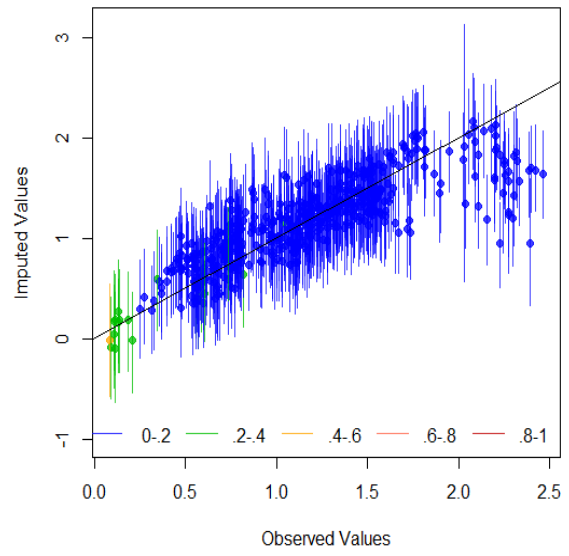


1.  $m = 5$  with added ID transformation for country and year variables

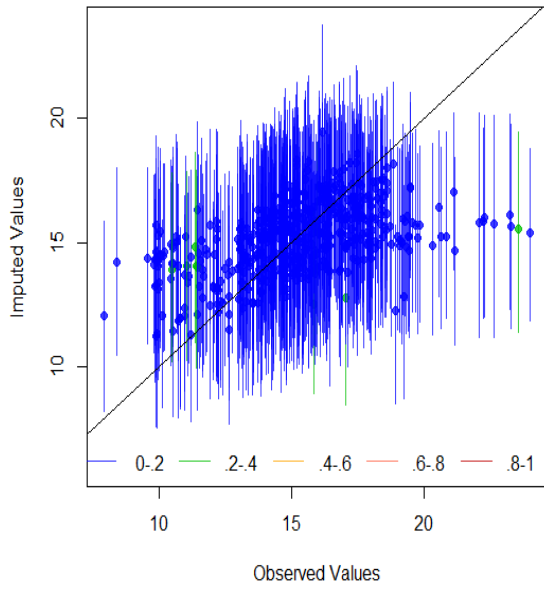
**Observed versus Imputed Values of RQ**



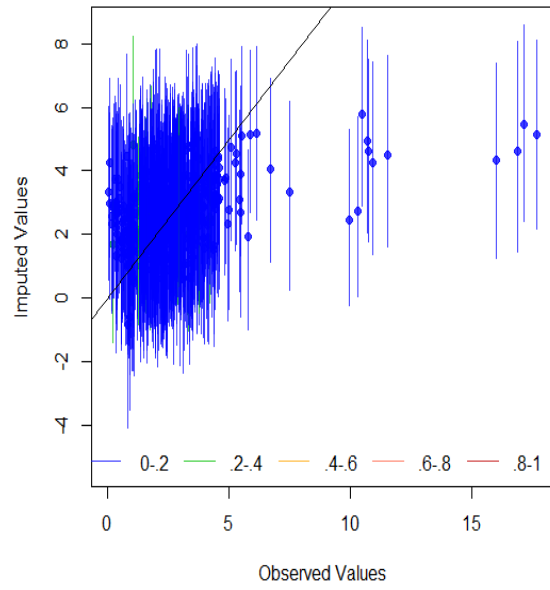
**Observed versus Imputed Values of RDPI**



**Observed versus Imputed Values of exp**

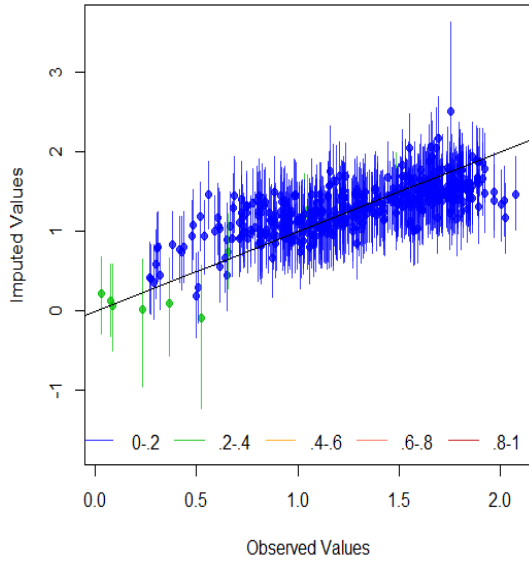


**Observed versus Imputed Values of ERGRDB**

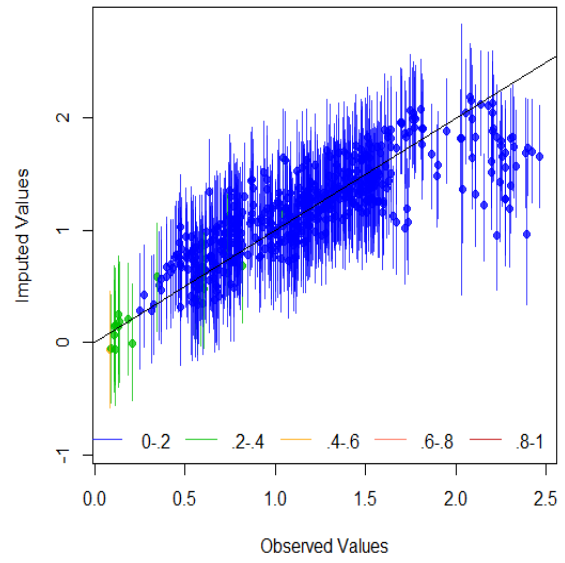


2.  $m = 20$  with added ID transformation for country and year variables

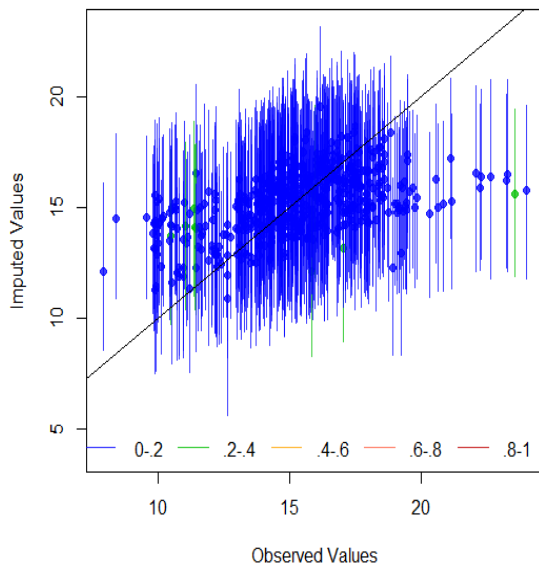
**Observed versus Imputed Values of RQ**



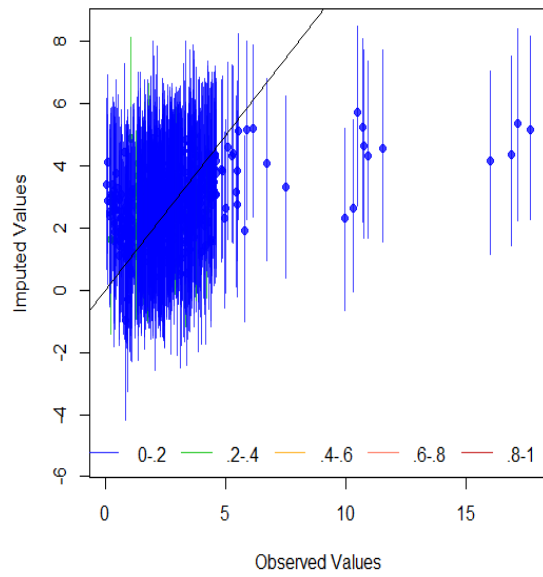
**Observed versus Imputed Values of RDPI**



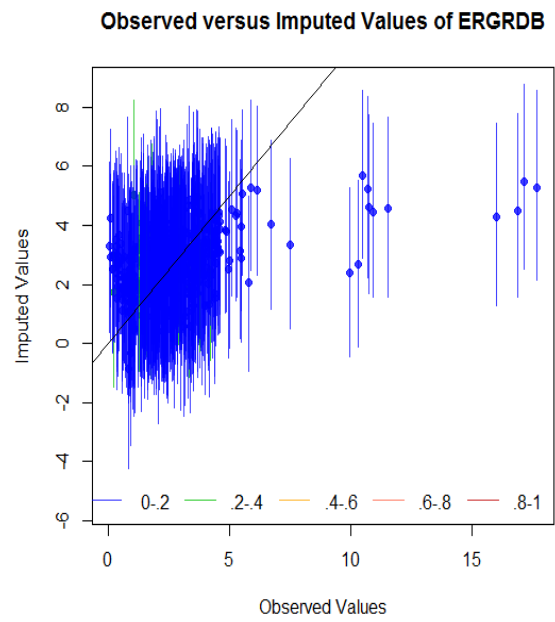
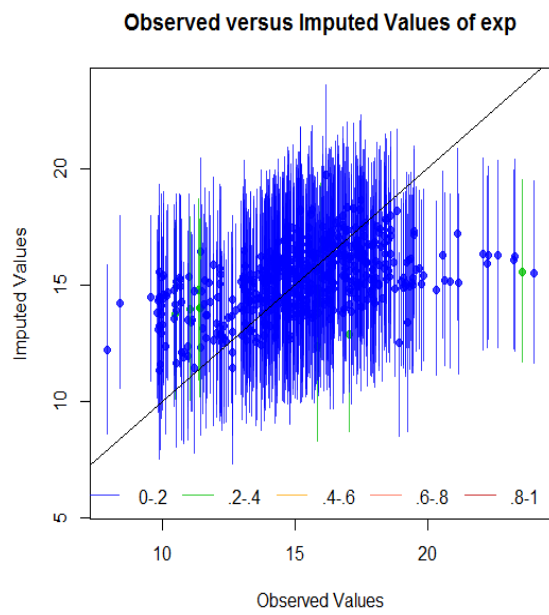
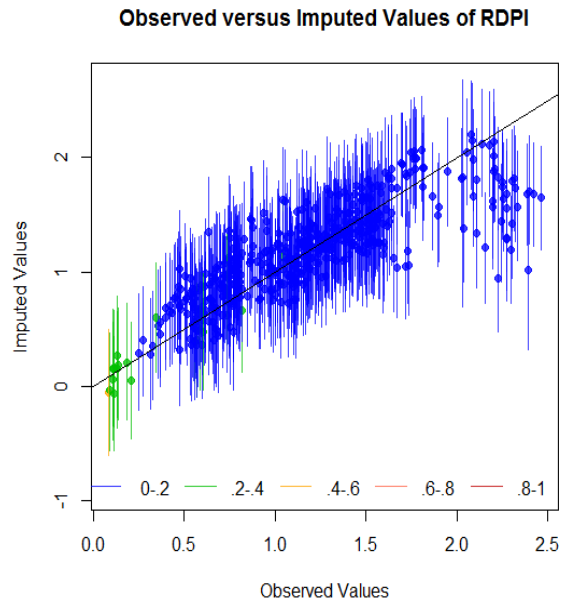
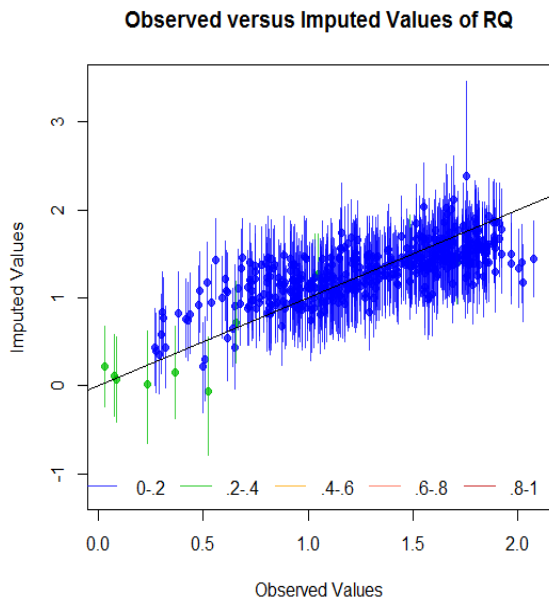
**Observed versus Imputed Values of exp**



**Observed versus Imputed Values of ERGRDB**



3.  $m = 40$  with added ID transformation for country and year variables



4.  $m = 100$  with added ID transformation for country and year variables

## Appendix (1.D)

### Variables Selection: QIC program

In order to determine whether certain or all the four groups of control explanatory variables that we determined before should be included in the (CRE) model, we run the *QIC* program<sup>32</sup> in generalized estimating equation (GEE) analyses for four scenarios. As the number of imputations in our database is equal to 100, so we have 100 databases imputed. For this reason, we calculate the value of *QIC* for every data base imputed and after that we calculate the average value of *QIC* for every scenario. The best fitting scenario (model) is the one that has the smallest *QIC* average. The four scenarios are as follow:

The first includes the share of environmentally related taxes revenues in GDP and conditioning variables. In the second, we add the variables of human capital to the first scenario. In the third, the variables of fiscal policy are added to the second scenario. Finally, we add the variables of macroeconomic control to the third scenario. Table (D.1) shows the descriptive statistics of *QIC* values for every scenario.

Variable	Obs	Mean	Std. Dev.	Min	Max
<b>QICS1</b>	100	301537.8	435.0818	301137.2	304337
<b>QICS2</b>	100	291369.6	333.9393	291062.4	293431.4
<b>QICS3</b>	100	265485.2	878.2393	264427.2	269870
<b>QICS4</b>	100	236990.5	472.0661	236384.2	239105.3

*Source: The author*

*Table D.1: The descriptive statistics of the values of QIC for every scenario*

We find that the best scenario is the fourth. It has the least value of the mean of *QIC* (236990.5). Therefore, the CRE equation contains all the explanatory variables.

---

<sup>32</sup> This program was developed by Cui and others (2007). The best fitting model and the best correlation structure can be selected by using the value of *QIC*. A subset of covariates with the smallest *QIC* will be the preferred model.



# Appendix (1.E)

## Multicollinearity and VIF test

Multicollinearity (correlation between predictors) can lead to: an “incorrect” parameter estimates sign or implausible magnitudes; a large increase in standard errors for coefficients; a model in which variables have low significance levels even though  $R^2$  is large; and/or create situations in which small changes in the data produce big swings in parameter estimates (Greene 2012). These problems can be severe and sometimes crippling. The Variance Inflation Factor (VIF) is widely used to measure the degree of  $ith$  independent variable multicollinearity with the other independent variables in a regression model<sup>33</sup>. VIF measures how much the variance (the square of the estimate's standard deviation) of an estimated regression coefficient is “inflated” because of linear dependence on other predictors.<sup>34</sup> The high value of the VIF index indicates that the variance of the estimated coefficient is high, which means that severe multicollinearity effects are present. (Kennedy 1992) notes that “for standardized data  $VIF_i > 10$  indicates harmful collinearity.” Consequently, we built our analyses on this rule. Table (1.E) shows the VIF values of our predictors. We can see that all the regressions have low VIF values indicating a low degree of multicollinearity. Therefore, there is no harmful collinearity between the explanatory variables.

Variable	VIF
<b>ETRT</b>	1.16
<b>lnY0</b>	1.11
<b>Change k</b>	1.08
<b>TLF</b>	1.19
<b>Ht-1</b>	1.39
<b>ChangeH</b>	1.06
<b>exp</b>	1.31
<b>tax</b>	1.51
<b>Balance</b>	1.33
<b>INF</b>	1.25
<b>OPENG</b>	1.14

Table 1.E: VIF values for predictors

<sup>33</sup> The formula of the *variance inflation factor* (VIF) is  $\frac{1}{1-R_k^2}$ ; where  $R_k^2$  is the unadjusted  $R^2$  obtained by regressing the  $k^{th}$  predictor on the remaining predictors in the model (see the site: <https://onlinecourses.science.psu.edu/stat501/node/347>).

<sup>34</sup> Please see the site: <http://support.minitab.com/en-us/minitab/17/topic-library/modeling-statistics/regression-and-correlation/model-assumptions/what-is-a-variance-inflation-factor-vif/>

## Appendix (1.F)

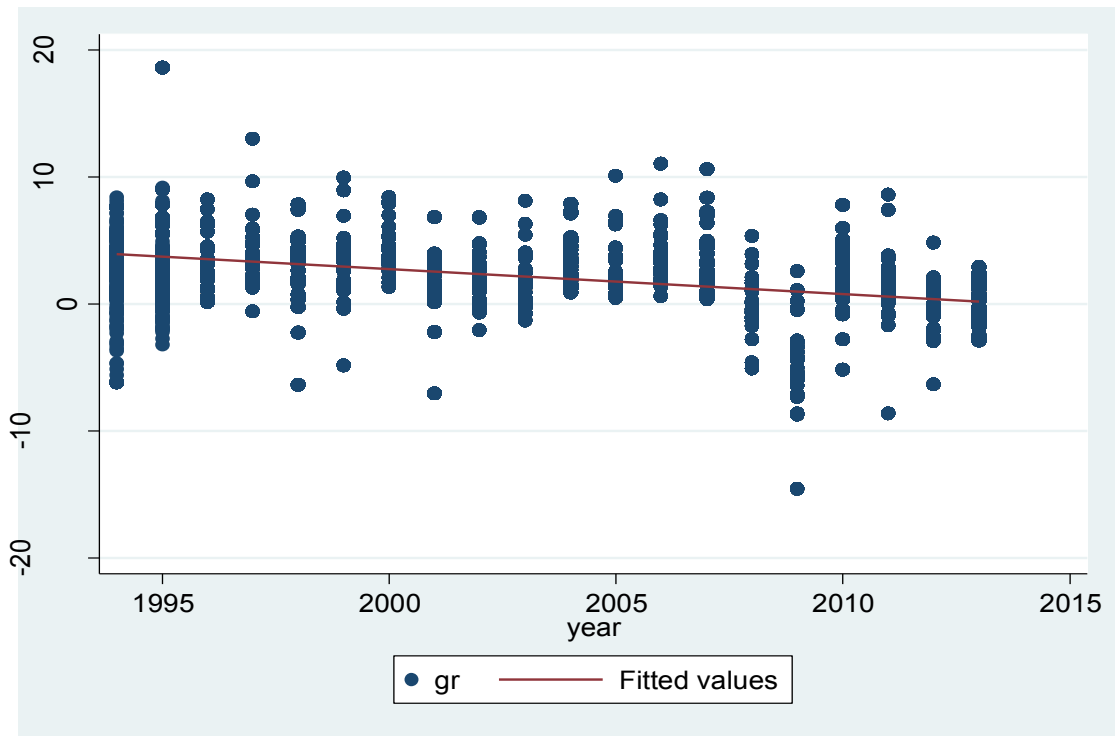
### Panel unit root tests

Given that one of the objectives in this chapter is to explore the nature of relation between environmentally related taxes and economic growth rate in the long run, we needed to verify whether the time series for economic growth rate (gr) and environmentally related taxes revenues (ETRT) were stationary. In order to achieve this goal, we ran a series of panel unit root tests. As the number of imputations (m) in our database was 100, there were 100 imputed databases. With the absence of a direct panel unit root test for 100 databases at the same time, we implemented the tests on the hundredth imputed database<sup>35</sup>. Before performing the tests, we produced a plot of time series of (gr) and (ETRT) which gave an idea of the overall levels and variability of the series. This enabled us to see whether there was any time trend in the series. If we observed a rising or decreasing time trend in the plot, the “*trend*” option was to be included in Stata commands for panel unit root tests for the variable<sup>36</sup>. In order to visualize the longitudinal data over time, we used a *twoway* graph which to show the relationship between the time and the values of a variable. In addition, we put the prediction from a linear regression of a variable for a year on top of the visualized data. Figure (1.F.1) shows the time series of gr using the *twoway* graph. It indicates a decreasing trend of (gr) over the time. Consequently, the trend option was included in panel unit root tests for (gr). Figure (1.F.2) shows the time series of ETRT using the *twoway* graph. We note that environmentally related taxes revenues don't have a clear rising or decreasing trend over the time; consequently, the trend option will not be included in panel unit root tests for (ETRT). In order to mitigate the impact of cross-sectional dependence, we remove the cross-sectional averages from the series by using the “*demean*” option in Stata command. This procedure was suggested by [Levin et al. \(2002\)](#).

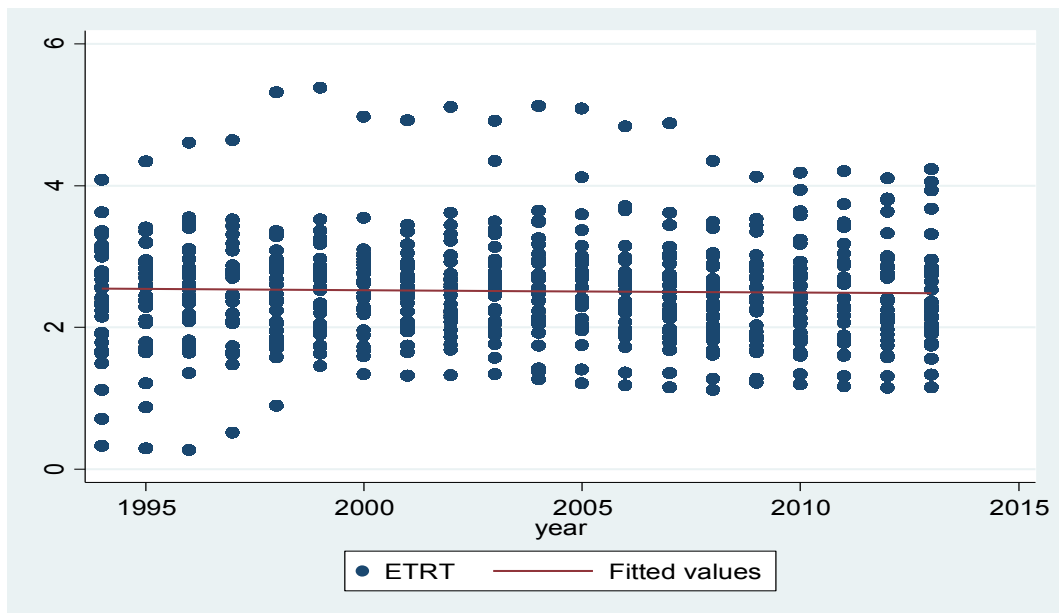
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<sup>35</sup> We ran these tests on an imputed database with m=5, 25, 50, 75,100. We obtained the same results.

<sup>36</sup> *Trend* includes a linear time trend in the model, which describes the process by which the series is generated. Please see : <http://www.stata.com/manuals13/xtxtunitroot.pdf>



*Figure 1.F.1: Time series of (gr) using the twoway graph*



*Figure 1.F.2: time series of ETRT using twoway graph*

Panel unit root tests could thus be implemented for (gr) and (ETRT) including “trend” and “demean” options for (gr), and only “demean” option for (ETRT). Table (1.F.1) presents the null hypothesis ( $H_0$ ) and the alternative hypothesis ( $H_a$ ) for every type of panel unit root tests. We notice that all these tests have the same null hypothesis.

Test	$H_0$	$H_a$
<b>Levin-Lin-Chu (2002)</b>	All panels contain unit roots	All panels are stationary
<b>Im-Pesaran-Shin (2003)</b>	All panels contain unit roots	Some panels are stationary
<b>Fisher-type (Choi 2001)</b>	All panels contain unit roots	At least one panel is stationary

*Table (1.F.1): Panel unit root tests hypotheses*

These various tests have differing assumptions about the rates at which the number of panels,  $N$ , and the number of time periods,  $T$ , tends to infinity or whether  $N$  or  $T$  are fixed. Table (1.F.2) presents these assumptions. As this paper deals with a macroeconomic analysis of OECD countries, we could assume that  $N$  is fixed whereas  $T$  tends to infinity. In this case, the Fisher-type test ((Choi 2001) would have been the appropriate test for our sample. However, our dataset included  $N > T$  where  $N = 31$  and  $T = 20$ , because data collected about environmentally-related taxes had been in place since 1994. In this situation, if we supposed that  $N$  and  $T$  were fixed, (Im, Pesaran, and Shin 2003) would have been the best test for our data. However, we ran all the tests, considering the other tests as robust tests.

Test	Option	Asymptotics
<b>Levin-Lin-Chu (2002)</b>	Trend, demean	$N/T \rightarrow 0$
<b>Im-Pesaran-Shin (2003)</b>	Trend, demean	$N \rightarrow \infty$ , $T$ fixed or $N$ and $T$ fixed
<b>Fisher-type (Choi 2001)</b>	Demean	$T \rightarrow \infty$ , $N$ finite or infinite

*Table 1.F.2: The assumptions of panel unit root tests about  $N$  and  $T$*

The results of stationary tests for economic growth rate and the environmentally related taxes revenues are reported in the tables (1.F.3) and (1.F.4) respectively. The three tests strongly rejected the null hypothesis that all the panels contain unit roots. Therefore, all panel’s series of (gr) and (ETRT) were stationary.

Test		Statistics	P-values	N	T
<b>Levin-Lin-Chu (2002)</b>	Adjusted t*	-3.7123	0.0001	31	20
<b>Im-Pesaran-Shin (2003)</b>	W-t-bar	-5.4286	0.0000	31	20
<b>Fisher-type (Choi 2001)</b>	P	182.6029	0.0000	31	20
	Z	-8.5012	0.0000		
	L*	-8.7033	0.0000		
	Pm	10.8305	0.0000		

*Table 1.F.3: The results of panel unit root tests for economic growth rate*

Test		Statistics	P-values	N	T
<b>Levin-Lin-Chu (2002)</b>	Adjusted t*	-2.6995	0.0035	31	20
<b>Im-Pesaran-Shin (2003)</b>	Z-t-tilde-bar	-2.2778	0.0114	31	20
<b>Fisher-type (Choi 2001)</b>	P	160.5550	0.0000	31	20
	Z	-7.0763	0.0000		
	L*	-7.2839	0.0000		
	Pm	8.8505	0.0000		

*Table 1.F.4: The results of panel unit root tests for environmentally related taxes revenues*

## Appendix (1.G)

The result of Variable Addition Test (VAT) of equation 1.4 in the short and long term

Null hypothesis	
(1)	ETRTbar = 0
(2)	Changekbar = 0
(3)	TLFbar = 0
(4)	H-t1bar = 0
(5)	ChangeHbar = 0
(6)	expbar = 0
(7)	taxbar = 0
(8)	Balancebar = 0
(9)	INFbar = 0
(10)	OPENGbar = 0
	F( 10,279878.2)= 3.10
<b>Prob &gt; F =</b>	<b>0.0006</b>

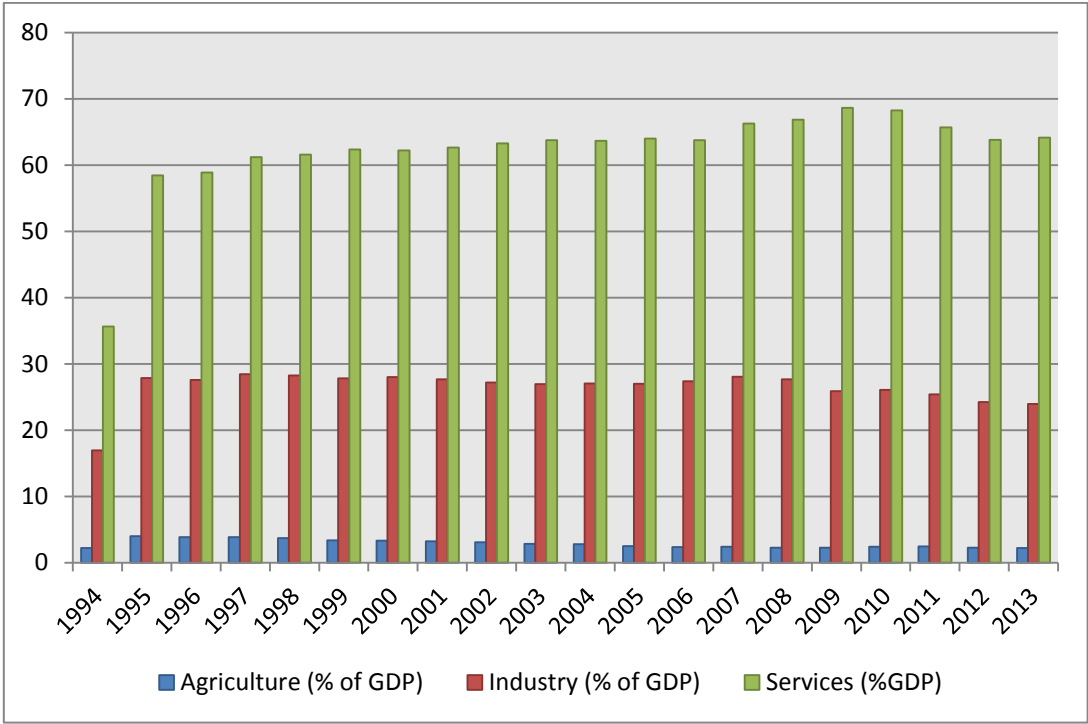
*Table 1.G.1. The result of Variable Addition Test (VAT) of equation 1.4 in the short term*

Null hypothesis					
	Lag=1	Lag=2	Lag=3	Lag=4	Lag=5
(1)	ETRTbar = 0	ETRTbar = 0	ETRTbar = 0	ETRTbar = 0	ETRTbar = 0
(2)	Changekbar = 0	Changekbar = 0	Changekbar = 0	Changekbar = 0	Changekbar = 0
(3)	TLFbar = 0	TLFbar = 0	TLFbar = 0	TLFbar = 0	TLFbar = 0
(4)	Ht_1bar = 0	Ht_1bar = 0	Ht_1bar = 0	Ht_1bar = 0	Ht_1bar = 0
(5)	ChangeHbar = 0	ChangeHbar = 0	ChangeHbar = 0	ChangeHbar = 0	ChangeHbar = 0
(6)	expbar = 0	expbar = 0	expbar = 0	expbar = 0	expbar = 0
(7)	taxbar = 0	taxbar = 0	taxbar = 0	taxbar = 0	taxbar = 0
(8)	Balancebar = 0	Balancebar = 0	Balancebar = 0	Balancebar = 0	Balancebar = 0
(9)	INFbar = 0	INFbar = 0	INFbar = 0	INFbar = 0	INFbar = 0
(10)	OPENGbar = 0	OPENGbar = 0	OPENGbar = 0	OPENGbar = 0	OPENGbar = 0
	F(10,776301.4) = 3.40	F(10,885557.5) = 4.62	F(10, 2.7e+06)= 5.41	F(10,416318.7) = 7.86	F(10,183397.4) = 2.98
<b>Prob &gt; F =</b>	<b>0.0002</b>	<b>0.0000</b>	<b>0.0000</b>	<b>0.0000</b>	<b>0.0000</b>

*Table 1.G.2. The result of Variable Addition Test (VAT) of equation 1.4 in the long term*

# Appendix (1.H)

Evolution of value added in agriculture, industry and services sectors



Source: Author’s calculation based on data from the World Bank.

*Evolution of value added in agriculture, industry and services sectors as % of GDP over time, OECD average (30 countries<sup>37</sup>).*

<sup>37</sup> When we calculated the average of value added in these sectors, Israel was excluded from our sample because it doesn’t have a data for added value as (% GDP) in agriculture, industry and services sectors.

## Chapter 2 Appendix

### Appendix (2.A): Summary and sources for variables

Code	Definitions	Data source
	<i>Dependent variable</i>	
gr	Annual percentage growth rate of GDP per capita based on purchasing power parity (PPP) at constant 2005 U.S. dollars is used as an indicator of economic growth rate per capita.	(WDIs, 2015)
	<i>Energy taxes proxy</i>	
ETR_MUSD	Energy tax revenues, in million USD, equal to the sum of revenue from taxes imposed on petrol and diesel for transport purposes, and taxes on fossil fuels and electricity for stationary purposes.	(OCDE, 2015)
Coal_Ktoe	Total final consumption of coal and coal products, in thousands of tons of oil equivalent.	(IEA, 2015)
Oil_Ktoe	Total final consumption of oil products, in thousands of tons of oil equivalent.	(IEA, 2015)
Gas_Ktoe	Total final consumption of natural gas, in thousands of tons of oil equivalent.	(IEA, 2015)
ELEC_Ktoe	Total final consumption of electricity, in thousands of tons of oil equivalent.	(IEA, 2015)
PELEC_%	The rate of total final consumption of electricity generated from oil, gas and coal sources (% of total electricity generated) during a given year.	(IEA, 2015)
TFCE_Ktoe	Total final consumption of energy, in thousands of tons of oil equivalent.	(IEA, 2015)
PELEC_Ktoe	Total final consumption of polluting electricity, in thousands of tons of oil equivalent. $PELEC\_Ktoe = ELEC\_Ktoe \times PELEC\_%$	Author
TFCPEP_Ktoe	Total final consumption of polluting energy products. $TFCPEP\_Ktoe = Coal\_Ktoe + Oil\_Ktoe + Gas\_Ktoe + PELEC\_Ktoe$	Author
ET	Proxy of energy taxes, tax revenue from energy taxes per unit of fossil fuel energy use, in US \$ per ton of oil equivalent <sup>38</sup>	Author

<sup>38</sup> Since energy tax revenues are measured in millions and total final consumption of polluting energy products in thousands, we multiply energy tax revenues by 1000 in order to convert it to thousands. To obtain energy tax



Code	Definitions	Data source
	$ET = \frac{ETR\_MUSD \times 1000}{TFCPEP\_Ktoe}$	
TFCPEP_sh	Share of total final consumption of polluting energy products in total final consumption of energy, $TFCPEP\_sh = \frac{TFCPEP\_Ktoe}{TFCE\_Ktoe} \times 100$	Author
	<i>Conditioning variables</i>	
Lny0	The natural logarithm of real GDP per capita for each country in the year 1994 <sup>39</sup> .	(WDIs, 2015)
k	Real gross fixed capital formation (% of GDP). (A proxy of physical capital).	(WDIs, 2015)
Change k	Annual change of physical capital. It is defined as $(k_t - k_{t-1})$ .	Author according to data from (WDIs, 2015)
TLF	Total labor force growth rate.	(WDIs, 2015)
	<i>Human capital</i>	
H	Human capital. The human-skill index is used as a proxy of human capital	(LEAD, 2015)
H <sub>t-1</sub>	The level of human capital in the previous year.	Author, according to data from (LEAD, 2015)
changeH	Annual change in human capital.	Author, according to data from (LEAD, 2015)
	<i>Fiscal policy</i>	
exp	Productive expenditure, defined as the sum of general government spending on education, health, housing, public order and safety, and defense as a percentage of GDP.	(OECD and GFS, 2015)
tax	Distortionary taxation. It is the sum of taxes imposed on income, profit and capital gains, payroll and workforce, as well as social security contributions as a percentage of GDP.	(OECD, 2015)
Balance	Fiscal balance (surplus/deficit) as a percentage of GDP.	(OECD, 2015)
	<i>Macro control variables</i>	

revenues in USD per ton of oil equivalent, we divide energy tax revenues measured in thousands by total final consumption of polluting energy products measured in thousands.

<sup>39</sup> The gross domestic product is measured at constant 2005 U.S. dollars and purchasing power parity (PPP).

<b>Code</b>	<b>Definitions</b>	<b>Data source</b>
INF	Inflation rate, is measured by the annual percentage change in the Consumer Price Index.	(WDIs, 2015)
OPENG	Openness to international trade of goods, is defined as (exports plus imports of goods) as percentage of GDP.	(OCDE, 2015)

**Source:** World Development Indicators (WDIs), World Governance Indicators (WGIs), Organization for Economic Co-operation and Development (OECD), Government Finance Statistics (GFS), and International Energy Agency (IEA). Data on human capital stock are performed by the “Laboratoire d’Économie Appliquée au Développement (LEAD)” in Toulon University (France).

*Table 2.A: Summary and sources for variables*

## Appendix (2.B)

### Variables Selection: QIC program

By following the same methodology that we used in the appendix (1.D) to determine whether certain or all the four groups of control explanatory variables should be included in the (CRE) model, we run the *QIC* program for four scenarios. The first includes the proxy of energy taxes and conditioning variables. In the second, we add the variables of human capital to the first scenario. In the third, the variables of fiscal policy are added to the second scenario. Finally, we add the variables of macro control to the third scenario. Table (2.B) shows the descriptive statistics of QIC values for every scenario. We find that the best scenario is the fourth. It has the least value of the mean of QIC (231405.6). Therefore, the CRE equation contains all the explanatory variables.

Variable	Obs	Mean	Std. Dev.	Min	Max
<b>QICS1</b>	100	283430.1	145.3388	283292.6	284329.6
<b>QICS2</b>	100	277289.8	219.5893	277108.7	278931.6
<b>QICS3</b>	100	254680	635.2565	253813	257857.7
<b>QICS4</b>	100	231405.6	477.4187	230776.2	233415.2

Source: The authors

*Table 2.B: The descriptive statistics of the values of QIC for every scenario*

## Appendix (2.C)

### Multicollinearity and VIF test

The analysis here is built on the same rule that we followed in the appendix (1.E). Consequently, the VIF test is run and the table (2.C.1) shows the results. We find that all the regressions have low values for VIF indicating a low degree of multicollinearity.

Variable	VIF
<b>ET</b>	1.46
<b>TFCPEP_sh</b>	1.43
<b>lnY0</b>	1.09
<b>OPENG</b>	1.18
<b>changek</b>	1.09
<b>TLF</b>	1.25
<b>Ht-1</b>	1.35
<b>ChangeH</b>	1.07
<b>exp</b>	1.31
<b>tax</b>	1.74
<b>Balance</b>	1.44
<b>INF</b>	1.27

*Table 2.C.1: VIF values of predictors*

# Appendix (2.D)

## Panel unit root tests

In the appendix (1.D) of chapter 1, we showed that the time series of economic growth rate is stationary. In this appendix, we test whether the time series of energy taxes proxy (ET) is stationary. To this end, we followed the same methodology used in the appendix (1.F). Firstly, we showed the relationship between the time and the values of energy taxes proxy by using a *twoway* graph. In addition, we put on top of visualized data the prediction from a linear regression of variable on year. The objective of this procedure was to know whether there is a rising or decreasing time trend in the plot. Figure (2.D) shows the time series of ET using the *twoway* graph. We observed that the proxy of energy taxes had a rising trend over the time. Consequently, the *trend* option had been included in panel unit root tests for (ET).

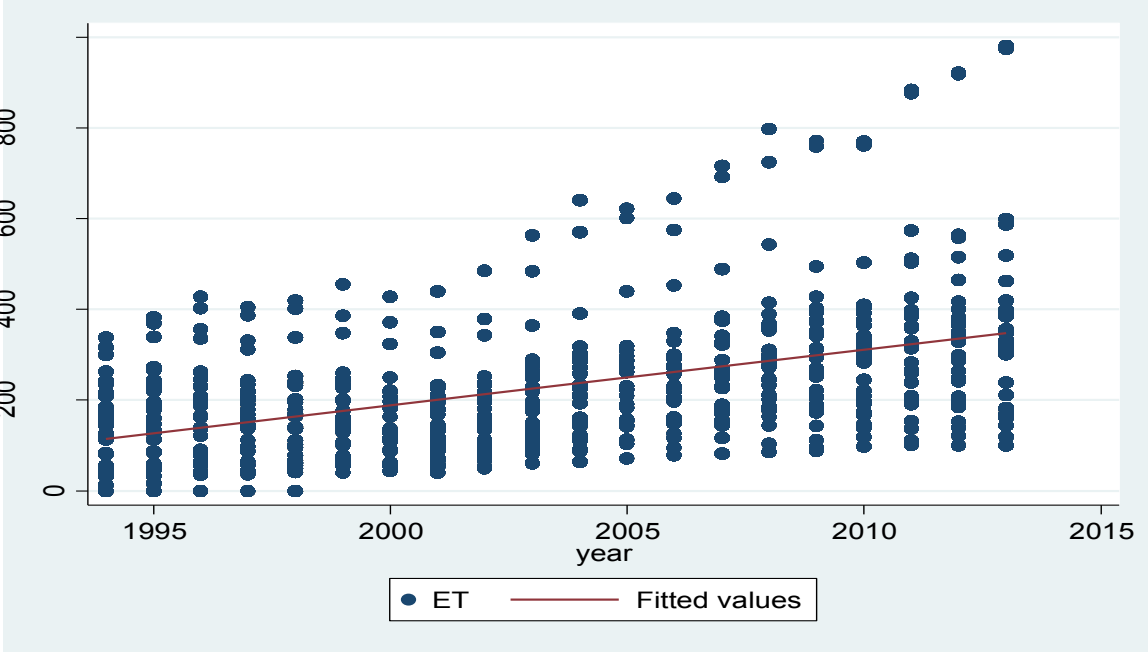


Figure 2.D. Time series of ET using *twoway* graph

Following the suggestion of Levin, Lin, and Chu (2002), the cross-sectional averages is removed from the series by using “*demean*” option in Stata command. Now, we can implement panel unit root tests for (ET), including “*trend*” and “*demean*” options. Based on the discussion that we did in the appendix (1.F) about the unit root tests which fit our sample, we used three tests. They are Levin, Lin, and Chu (2002); Im, Pesaran, and Shin (2003); and Ficher-type Choi (2001).

The results of these tests are reported in tables (2.D). The results showed that p-values for Fisher-type Choi (2001) tests are less than 0.01. For Levin, Lin, and Chu (2002) and Im, Pesaran, and Shin (2003) tests, p-value is less than 0.05. Consequently, at a 5% critical value, we rejected the null hypothesis that all panel's series of (ET) contain a unit root. Thereby, the proxy of energy based taxes had stationary panel series.

Test		Statistics	P-values	N	T
<b>Levin-Lin-Chu (2002)</b>	Adjusted t*	-1.972	0.0243	31	20
<b>Im-Pesaran-Shin (2003)</b>	W-t-bar	-1.8073	0.0354	31	20
<b>Fisher-type (Choi 2001)</b>	P	110.9507	0.0001	31	20
	Z	-3.2029	0.0007		
	L*	-3.2709	0.0007		
	Pm	4.3959	0.0000		

Table 2.D: The results of panel unit root tests for the proxy of energy taxes

### Appendix (2.E)

The results of Variable Addition Test (VAT), equation 2.2 and 2.3 (before and after MI)

	Before MI	After MI
	Null hypothesis	Null hypothesis
(1)	ETbar = 0	ETbar = 0
(2)	changekbar = 0	changekbar = 0
(3)	TLFbar = 0	TLFbar = 0
(4)	Ht_1bar = 0	Ht_1bar = 0
(5)	ChangeHbar = 0	ChangeHbar = 0
(6)	expbar = 0	expbar = 0
(7)	taxbar = 0	taxbar = 0
(8)	Balancebar = 0	Balancebar = 0
(9)	INFbar = 0	INFbar = 0
(10)	OPENGbar = 0	OPENGbar = 0
	chi2( 12) = 33.83	F(10,614128.4) = 3.67
	Prob > chi2 = 0.0002	Prob > F = 0.0001

Table 2. E.1: The results of Variable Addition Test (VAT), equation 2.2 (before and after MI)

	Before MI	After MI
	Null hypothesis	Null hypothesis
(1)	ETbar = 0	ETbar = 0
(2)	TFCPEP_shbar = 0	TFCPEP_shbar = 0
(3)	OPENGbar = 0	OPENGbar = 0
(4)	changekbar = 0	changekbar = 0
(5)	TLFbar = 0	TLFbar = 0
(6)	Ht-1bar = 0	Ht-1bar = 0
(7)	ChangeHbar = 0	ChangeHbar = 0
(8)	expbar = 0	expbar = 0
(9)	taxbar = 0	taxbar = 0
(10)	Balancebar = 0	Balancebar = 0
(11)	INFbar = 0	INFbar = 0
	chi2( 11) = 25.66	F(11,585050.5) = 2.26
	Prob > chi2 = 0.0073	Prob > F = 0.0095

Table 2. E.2: The results of Variable Addition Test (VAT) test, equation 2.3 (before and after MI)

## Chapter 3 Appendix

### Appendix 3.A: Summary and source of variables

Code	Definitions	Data source
gr	Annual percentage growth rate of GDP per capita based on purchasing power parity (PPP) at constant 2005 U.S. dollars is used as an indicator of economic growth rate per capita.	(WDIs, 2015)
ET	Proxy of energy taxes, tax revenue from energy taxes per unit of fossil fuel energy use, in US \$ per ton of oil equivalent. (Appendix 2.A in chapter 2 provides the details of calculation)	Author
TFCPEP_sh	Total final consumption share of polluting energy products in total final consumption of energy (Appendix 2.A in chapter 2 provides the details of calculation)	Author
k	Real gross fixed capital formation (% of GDP)	(WDIs, 2015)
Change k	The annual change in real gross fixed capital formation (% of GDP)	Author, according to data from (WDIs, 2015)
H	Human capital. The human-skill index is used as a proxy of human capital	(LEAD, 2015)
$H_{t-1}$	The initial level of human capital measured as the value of human capital in the previous year	Author, according to data from (LEAD, 2015)
changeH	Annual change in human capital.	Author, according to data from (LEAD, 2015)
EINNOV	Environmental innovation measured by the development of environment-related technologies as a percentage of all technologies.	(OECD, 2016)
Lny0	The natural logarithm of real GDP per capita for each country in the year 1994 <sup>40</sup> .	(WDIs, 2015)
TLF	Total labor force growth rate.	(WDIs, 2015)
Exp	Productive expenditure, defined as the sum of general government spending on education, health, housing, public order and safety, and defense as a percentage of GDP.	(OECD and GFS, 2015)

<sup>40</sup> The gross domestic product is measured at constant 2005 U.S. dollars and purchasing power parity (PPP).



Code	Definitions	Data source
Tax	Distortionary taxation. It is the sum of taxes imposed on income, profit and capital gains, payroll and workforce, as well as social security contributions as a percentage of GDP.	(OECD, 2015)
Balance	Fiscal balance (surplus/deficit) as a percentage of GDP.	(OECD, 2015)
INF	Inflation rate, is measured by the annual percentage change in the Consumer Price Index.	(WDIs, 2015)
OPENG	Openness to international trade of goods, is defined as (exports plus imports of goods) as percentage of GDP.	(OECD, 2015)
DCPS	Domestic credit to private sector, as a percentage of GDP	(WDIs, 2017)
RQ	Regulatory quality	(WGIs, 2017)
GNS	Gross national saving, as a percent of GDP	(WEOD, 2017)
CO2	Carbon dioxide emissions measured in (kt)	(WDIs, 2017)
FERT	Total fertility rate, (births per woman)	(WDIs, 2017)
TID	Technology-Infrastructure development measured by Technology-Infrastructure Index	(LEAD, 2017)
Y	Real GDP per head, constant prices, constant PPPs, OECD base year is 2010	(OECD, 2017)
LPop	Logarithm of all population	(OECD, 2017)
ERGRDB	Environmentally-related government R&D budget as a percentage of total government R&D	(OECD, 2017)
FDI	Foreign direct investment, net inflows (% of GDP)	(WDIs, 2017)
RDPI	R&D personnel intensity=(R&D personnel/employments)*100	Author, according to data from (OECD, 2017)
<p><b>Source:</b> World Development Indicators (WDIs), World Governance Indicators (WGIs), Organization for Economic Co-operation and Development (OECD), Government Finance Statistics (GFS), World Economic Outlook Database (WEOD), and International Energy Agency (IEA). Data on Human capital stock are performed by “Laboratoire d’Économie Appliquée au Développement (LEAD)” in Toulon university (France).</p>		

*Table 3.A: Summary and source of variables*

### Appendix (3.B)

#### Multicollinearity and VIF test

As mentioned in the appendix (1.E), we follow the rule of (Kennedy 1992) to decide whether there is a harmful collinearity between the explanatory variables. The rule is that, if the value of VIF is greater than 10, this means that there is a harmful collinearity. The tables (3.B.1- 4) report the values of VIF for each of model’s equations. The results show that all the regressions have low values for VIF indicating a low degree of multicollinearity. Therefore, there is not harmful collinearity between the explanatory variables for each equation in the model.

Variable	VIF
Change k	1.08
Ht-1	1.33
ChangeH	1.06
EINNOV	1.17
lnY0	1.20
TLF	1.19
exp	1.31
tax	1.49
Balance	1.33
INF	1.27
OPENG	1.12

*Table 3.B.1: VIF values for predictors in the economic growth equation*

Variable	VIF
ET	1.53
exp	1.19
tax	1.90
DCPS	1.81
RQ	1.94
GNS	1.25
DEBT	1.53

*Table 3.B.2: VIF values for predictors in investment equation*

Variable	VIF
LCO2	1.09
exp	1.21
FERT	1.34
TID	1.15
RQ	1.15

*Table 3.B.3: VIF values for predictors in human capital equation*

Variable	VIF
ET	1.65
Y	1.58
TFCPEP_sh	1.79
LPop	1.96
OPENG	1.23

*Table 3.B.4: VIF values for predictors in environmental innovation equation*

### Appendix (3.C)

#### Correlation between the instruments and error

To examine whether the instruments are correlated with the error term of the structural equation, Roodman and Morduch (2014) add them linearly to the structural equation (the second-stage equation). An F-test is then conducted to see whether the instruments are jointly significant. If the instruments are not jointly significant, this means that they are not correlated with the error term. Thus, the first condition of instrument validity is satisfied. To apply this test on our instruments, we added GNS, FERT, FDI and RDPI linearly to the economic growth equation and ET to the human capital equation. In this case, our model would still identify, because the equations were over-identified as we see in appendix (D). We then estimated the model and we conducted an F-test for GNS, FERT, FDI and FDPI. The results of the F-test are presented in table (3.C). They show that the coefficients of GNS, FERT, FDI and RDPI are jointly equal to zero. Therefore, these instruments do not directly affect the economic growth rate, and thus they are not correlated to the error term of (gr). In addition, estimation results show that the P-value of (ET) in the human capital equation is equal to 0.305, indicating that the proxy of energy taxes is not correlated with human capital. Consequently, these results show that our instruments satisfy the first condition of validity. However, the results must be regarded with caution in view of the fact that only 9 out of 100 imputations were taken into account when we conducted this test.

Null hypothesis	
(1)	[gr]GNS = 0
(2)	[gr]FERT = 0
(3)	[gr]FDI = 0
(4)	[gr]RDPI = 0
F (4, 437.7) = 1.59	
Prob > F = 0.1767	

Table 3.C: F-test results

## Appendix (3.D)

### The order and rank conditions

#### D.1 The order condition for identification

In order to be able to estimate the system equations coefficients, each equation in the system need to be identified. This is called the order condition for identification. An equation in a system of equations is said to be identified, if the number of excluded exogenous variables from this equation is at least as great as the number of right-hand side endogenous variables included in this equation (Wooldridge, 2013). To make this condition clearer, let us suppose that:

- $K$  is the number of all exogenous variables included in the model (system), and  $k$  is the number of exogenous variables included in the equation under consideration.  $(K - k)$  represents the number of exogenous variables excluded from the equation under consideration.
- $M$  is the number of endogenous variables included in the right-side of the equation under consideration.

The order condition requires that:  $(K - k) \geq M$ .

If  $(K - k) < M$ , the equation under consideration is not *identified*.

If  $(K - k) = M$ , the equation under consideration is *exactly identified*.

If  $(K - k) > M$ , the equation under consideration is *over-identified*.

The order condition is used to verify that each equation in our model is over-identified (please see table (3.D.1)).

Equations	$K$	$k$	$(K - k)$	$M$	Identified?
Economic growth	20	7	13	3	Over-identified
Investment	20	6	14	0	Over-identified
Human capital	20	4	16	1	Over-identified
Dioxide carbon emissions	20	5	15	0	Over-identified
Environmental innovation	20	5	15	0	Over-identified

Table 3.D.1: Order condition verification

### 3.D.2 The rank condition for identification

The aim of the order condition is simply to verify whether sufficient variables have been excluded from an equation for identification. However, this condition does not verify whether the excluded variable appear anywhere in the system. The role of rank condition is to check that not only sufficient exclusion restrictions have been implemented, but also that the variables excluded actually do something in the rest of the model. Consequently, if a model contains  $M$  endogenous variables and  $M$  equations, an equation is identified by the rank condition if and only if at least one non-zero determinant of order  $(M - 1) \times (M - 1)$  can be constructed from the coefficients of the variables excluded from that equation (Asteriou and Hall, 2011). This condition requires the matrix of all structural equations of the model to have full rank.

The *checkreg3* command in Stata software is used to check whether the rank condition is satisfied for each of the  $M$  equations in the system (Baum, 2007). Table 3.D.2 and table 3.D.3 show the results of this command, which indicate that our simultaneous equations system is identified. The value of 0.5 is used only as placeholder to check the identification status.

	gr	k	H	LCO2	EINNOV
gr	-1	0	0	0	0.5
k	0	-1	0	0	0
H	0	0	-1	0.5	0
LCO2	0	0	0	-1	0
EINNOV	0	0	0	0	-1

Table 3.D.2: Endogenous coefficients matrix

	Change k	lnHt-1	changeH	lnY0	TLF	exp	tax	Balance	INF	OPENG	ET
gr	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0
k	0	0	0	0	0	0.5	0.5	0	0	0	0.5
H	0	0	0	0	0	0.5	0	0	0	0	0
LCO2	0	0	0	0	0	0	0	0	0	0.5	0.5
EINNOV	0	0	0	0	0	0	0	0	0	0	0.5

	DCPS	RQ	GNS	FERT	TID	Y	TFCPEP_sh	LPop	ERGRDB	FDI	RDPI
gr	0	0	0	0	0	0	0	0	0	0	0
k	0.5	0.5	.5	0	0	0	0	0	0	0	0
H	0	0.5	0	0.5	0.5	0	0	0	0	0	0
LCO2	0	0	0	0	0	0.5	0.5	0.5	0	0	0
EINNOV	0	0	0	0	0	0	0.5	0	0.5	0.5	0.5

*Table 3.D.3: Exogenous coefficients matrix*

Eq 1 is identified; Eq 2 is identified; Eq 3 is identified; Eq 4 is identified; Eq 5 is identified.

The system is identified

## Appendix (3.H)

### Estimations results when we use ACO2 instead of CO2 in the model

#### In the short term

	<i>Benchmark</i>	<i>Alternative specification</i>	
	<i>model</i>	<i>Model A</i>	<i>Model B</i>
<b>Economic growth equation</b>	Annual percentage growth rate of GDP per capita		
Change k	<b>0.163***</b> (0.054)	<b>0.158***</b> (0.055)	<b>0.158***</b> (0.055)
Ht-1	<b>48.724**</b> (19.153)	<b>45.343**</b> (19.115)	<b>45.199**</b> (19.142)
Change H	<b>73.049***</b> (22.032)	<b>69.804***</b> (21.938)	<b>69.550***</b> (21.959)
EINNOV	<b>-1.245***</b> (0.414)	<b>-1.247***</b> (0.425)	<b>-1.249***</b> (0.425)
lnY0	-0.960 (1.740)	-1.110 (1.733)	-1.102 (1.733)
TLF	4.046 (7.910)	4.666 (7.911)	4.714 (7.912)
Exp	<b>-0.367***</b> (0.085)	<b>-0.358***</b> (0.084)	<b>-0.358***</b> (0.084)
Tax	-0.082 (0.070)	-0.083 (0.070)	-0.083 (0.070)
Balance	<b>0.081**</b> (0.038)	<b>0.087**</b> (0.037)	<b>0.087**</b> (0.037)
INF	<b>-0.041**</b> (0.018)	<b>-0.043**</b> (0.019)	<b>-0.043**</b> (0.019)
OPENG	<b>0.029***</b> (0.008)	<b>0.029***</b> (0.008)	<b>0.029***</b> (0.008)
<b>Physical investment equation</b>	Real gross fixed capital formation		
ET	<b>-0.006***</b> (0.001)	<b>-0.007***</b> (0.001)	<b>-0.005***</b> (0.002)
DEBT		<b>-0.055***</b> (0.007)	<b>-0.042***</b> (0.011)
ET#DEBT			<b>-0.00005*</b> (0.000)
Exp	-0.108 (0.093)	-0.057 (0.093)	-0.065 (0.094)
Tax	<b>-0.152**</b> (0.072)	-0.012 (0.072)	-0.008 (0.071)
DCPS	<b>0.029***</b> (0.004)	<b>0.018***</b> (0.004)	<b>0.018***</b> (0.004)
RQ	<b>4.325***</b> (0.757)	<b>3.104***</b> (0.759)	<b>2.870***</b> (0.777)
GNS	<b>0.091**</b> (0.038)	-0.002 (0.039)	-0.010 (0.039)
<b>Human capital equation</b>	Human-skill index		
LACO2	<b>-0.010***</b> (0.001)	<b>-0.010***</b> (0.001)	<b>-0.010***</b> (0.001)
Exp	<b>0.001**</b>	<b>0.001**</b>	<b>0.001**</b>



	<i>Benchmark model</i>	<i>Alternative specification</i>	
		<i>Model A</i>	<i>Model B</i>
FERT	(0.0005) <b>-0.026***</b>	(0.0005) <b>-0.026***</b>	(0.0005) <b>-0.026***</b>
TID	(0.006) <b>0.131***</b>	(0.006) <b>0.134***</b>	(0.006) <b>0.134***</b>
RQ	(0.026) <b>0.012***</b>	(0.026) <b>0.011**</b>	(0.026) <b>0.011**</b>
	(0.004)	(0.004)	(0.004)
<b>LACO2 equation</b>	Logarithm of accumulated carbon dioxide emissions		
ET	<b>-0.002***</b> (0.0005)	<b>-0.002***</b> (0.0005)	<b>-0.002***</b> (0.0005)
Y	<b>0.00005***</b> (0.000)	<b>0.00005***</b> (0.000)	<b>0.00005***</b> (0.000)
TFCPEP_sh	<b>0.074***</b> (0.010)	<b>0.074***</b> (0.010)	<b>0.074***</b> (0.010)
LPOP	<b>9.072***</b> (0.797)	<b>9.074***</b> (0.800)	<b>9.062***</b> (0.799)
OPENG	-0.003 (0.002)	-0.003 (0.002)	-0.030 (0.002)
<b>Environmental innovation equation</b>	Development of environment-related technologies		
ET	<b>0.006***</b> (0.001)	<b>0.006***</b> (0.001)	<b>0.006***</b> (0.001)
ERGRDB	-0.070 (0.058)	-0.070 (0.058)	-0.071 (0.058)
FDI	<b>0.009*</b> (0.005)	<b>0.009*</b> (0.005)	<b>0.009*</b> (0.005)
TFCPEP_sh	-0.041 (0.033)	-0.038 (0.033)	-0.038 (0.032)
RDPI	<b>1.524**</b> (0.640)	<b>1.526**</b> (0.646)	<b>1.524**</b> (0.645)
Observations	620	620	620
Number of countries	31	31	31

Note: \*, \*\*, and \*\*\* indicates the significance level at 10, 5, and 1% respectively based on the two-tailed test. Standard error estimates are in parentheses. The country-specific effect ( $\eta_i$ ), the time-specific effect ( $\lambda_t$ ), and the constant were included in the regressions of each equation in the model but they are not presented in this table.

*Table 3.H.1: Estimations results in the short term, when we use ACO2 instead of CO2*

### In the long-term

	<i>Lags=1</i>			<i>Lags=2</i>			<i>Lags=3</i>		
	<i>Benchmark</i>	<i>Alternative specification</i>		<i>Benchmark</i>	<i>Alternative specification</i>		<i>Benchmark</i>	<i>Alternative specification</i>	
	<i>model</i>	<i>Model A</i>	<i>Model B</i>	<i>model</i>	<i>Model A</i>	<i>Model B</i>	<i>model</i>	<i>Model A</i>	<i>Model B</i>
<b>Economic growth equation</b> Annual percentage growth rate of GDP per capita									
Change k	<b>0.168**</b> (0.065)	<b>0.147**</b> (0.066)	<b>0.143**</b> (0.066)	-0.080 (0.066)	-0.104 (0.067)	-0.0109 (0.067)	-0.001 (0.062)	-0.012 (0.062)	-0.016 (0.062)
Ht-1	0.417 (9.841)	-0.981 (9.846)	-1.072 (9.836)	-6.737 (8.125)	-8.142 (8.083)	-8.275 (8.069)	-0.495 (7.100)	-1.170 (7.067)	-1.280 (7.063)
Change H	<b>27.093*</b> (14.457)	<b>26.675*</b> (14.415)	<b>26.517*</b> (14.402)	-12.094 (13.436)	-12.954 (13.338)	-13.478 (13.323)	10.114 (12.458)	11.113 (11.491)	10.729 (11.476)
EINNOV	0.026 (0.035)	0.029 (0.035)	0.029 (0.035)	<b>0.080**</b> (0.036)	<b>0.083**</b> (0.036)	<b>0.082**</b> (0.036)	<b>0.094**</b> (0.037)	<b>0.093**</b> (0.037)	<b>0.092**</b> (0.037)
lnY0	-0.899 (2.536)	-1.002 (2.523)	-0.961 (2.522)	2.252 (2.503)	2.616 (2.494)	2.642 (2.491)	1.217 (2.314)	1.391 (2.306)	1.407 (2.306)
TLF	1.506 (8.514)	2.783 (8.519)	3.091 (8.524)	<b>-22.929**</b> (9.020)	<b>-20.762**</b> (9.008)	<b>-20.179**</b> (9.015)	<b>-31.636***</b> (9.113)	<b>-30.128***</b> (9.088)	<b>-29.799***</b> (9.080)
exp	-0.130 (0.084)	-0.129 (0.084)	-0.130 (0.084)	-0.078 (0.086)	-0.075 (0.086)	-0.076 (0.086)	-0.090 (0.088)	-0.085 (0.088)	-0.084 (0.088)
tax	-0.023 (0.070)	-0.020 (0.070)	-0.021 (0.070)	-0.038 (0.074)	-0.035 (0.074)	-0.036 (0.074)	-0.025 (0.075)	-0.024 (0.075)	-0.027 (0.075)
Balance	0.015 (0.040)	0.017 (0.040)	0.017 (0.040)	0.033 (0.042)	0.037 (0.042)	0.037 (0.042)	-0.033 (0.043)	-0.028 (0.042)	-0.026 (0.042)
INF	<b>-0.052***</b> (0.015)	<b>-0.055***</b> (0.015)	<b>-0.055***</b> (0.015)	<b>-0.056***</b> (0.015)	<b>-0.059***</b> (0.015)	<b>-0.060***</b> (0.015)	<b>-0.059***</b> (0.016)	<b>-0.061***</b> (0.015)	<b>-0.061***</b> (0.015)
OPENG	<b>0.031***</b> (0.009)	<b>0.033***</b> (0.009)	<b>0.033***</b> (0.009)	<b>0.016*</b> (0.010)	<b>0.018*</b> (0.009)	<b>0.018*</b> (0.009)	<b>0.016*</b> (0.010)	<b>0.017*</b> (0.010)	<b>0.017*</b> (0.010)
<b>Physical investment equation</b> Real gross fixed capital formation as a percent of GDP									
ET	<b>-0.007***</b> (0.002)	<b>-0.008***</b> (0.001)	<b>-0.005***</b> (0.002)	<b>-0.009***</b> (0.002)	<b>-0.009***</b> (0.002)	<b>-0.006**</b> (0.002)	<b>-0.011***</b> (0.002)	<b>-0.011***</b> (0.002)	<b>-0.007***</b> (0.002)
DEBT		<b>-0.052***</b> (0.008)	<b>-0.032***</b> (0.011)		<b>-0.049***</b> (0.009)	<b>-0.025***</b> (0.012)		<b>-0.040***</b> (0.009)	-0.016 (0.013)
ET#DEBT			<b>-0.0001**</b> (0.000)			<b>-0.0001***</b> (0.000)			<b>-0.0001**</b> (0.000)
exp	<b>-0.207**</b> (0.091)	<b>-0.154*</b> (0.091)	<b>-0.163*</b> (0.091)	<b>-0.255***</b> (0.094)	<b>-0.201**</b> (0.094)	<b>-0.201**</b> (0.093)	<b>-0.164*</b> (0.093)	-0.121 (0.094)	-0.126 (0.093)
tax	<b>-0.135*</b> (0.074)	-0.015 (0.074)	-0.013 (0.073)	<b>-0.131*</b> (0.076)	-0.026 (0.076)	-0.023 (0.075)	-0.115 (0.076)	-0.027 (0.077)	-0.018 (0.076)
DCPS	<b>0.026***</b> (0.004)	<b>0.016***</b> (0.004)	<b>0.016***</b> (0.004)	<b>0.016***</b> (0.004)	0.006 (0.004)	0.006 (0.004)	0.004 (0.004)	-0.003 (0.004)	-0.004 (0.004)
RQ	<b>4.356***</b> (0.745)	<b>3.353***</b> (0.744)	<b>3.025***</b> (0.758)	<b>3.762***</b> (0.746)	<b>2.960***</b> (0.747)	<b>2.645***</b> (0.754)	<b>2.484***</b> (0.760)	<b>2.042***</b> (0.755)	<b>1.819**</b> (0.755)
GNS	<b>0.165***</b> (0.039)	<b>0.074*</b> (0.040)	0.062 (0.040)	<b>0.203***</b> (0.040)	<b>0.121***</b> (0.042)	<b>0.109***</b> (0.042)	<b>0.291***</b> (0.041)	<b>0.233***</b> (0.043)	<b>0.228***</b> (0.043)
<b>Human capital equation</b> Human-skill index									
LACO2	<b>-0.005***</b> (0.001)	<b>-0.005***</b> (0.001)	<b>-0.005***</b> (0.001)	<b>-0.003***</b> (0.001)	<b>-0.003***</b> (0.001)	<b>-0.003***</b> (0.001)	<b>-0.003***</b> (0.001)	<b>-0.003***</b> (0.001)	<b>-0.003***</b> (0.001)
exp	<b>0.001**</b> (0.0005)	<b>0.001**</b> (0.0005)	<b>0.001*</b> (0.0005)	<b>0.001*</b> (0.0005)	<b>0.001*</b> (0.0005)	<b>0.001*</b> (0.0005)	0.0005 (0.0005)	0.0005 (0.0005)	0.0007 (0.0005)
FERT	<b>-0.019***</b> (0.006)	<b>-0.019***</b> (0.006)	<b>-0.019***</b> (0.006)	<b>-0.014**</b> (0.006)	<b>-0.014**</b> (0.006)	<b>-0.014**</b> (0.006)	<b>-0.012**</b> (0.006)	<b>-0.012**</b> (0.006)	<b>-0.012**</b> (0.006)
TID	<b>0.138***</b> (0.027)	<b>0.140***</b> (0.028)	<b>0.139***</b> (0.028)	<b>0.127***</b> (0.028)	<b>0.128***</b> (0.028)	<b>0.128***</b> (0.028)	<b>0.119***</b> (0.028)	<b>0.120***</b> (0.028)	<b>0.119***</b> (0.028)
RQ	0.006 (0.004)	0.007 (0.004)	0.006 (0.004)	0.002 (0.004)	0.002 (0.004)	0.002 (0.004)	0.004 (0.004)	0.004 (0.004)	0.004 (0.004)

	<i>Lags=1</i>			<i>Lags=2</i>			<i>Lags=3</i>		
	<i>Benchmark model</i>	<i>Alternative specification</i>		<i>Benchmark model</i>	<i>Alternative specification</i>		<i>Benchmark model</i>	<i>Alternative specification</i>	
		<i>Model A</i>	<i>Model B</i>		<i>Model A</i>	<i>Model B</i>		<i>Model A</i>	<i>Model B</i>
<b>ACO2 equation</b>	Logarithm of accumulated carbon dioxide emissions								
ET	<b>-0.001***</b> (0.0005)	<b>-0.001***</b> (0.0005)	<b>-0.001***</b> (0.0005)	<b>-0.001**</b> (0.0005)	<b>-0.001**</b> (0.0005)	<b>-0.001**</b> (0.0005)	<b>-0.001**</b> (0.0006)	<b>-0.001**</b> (0.0006)	<b>-0.001**</b> (0.0006)
Y	<b>0.0001***</b> (0.000)	<b>0.0001***</b> (0.000)	<b>0.0001***</b> (0.000)	<b>0.0001***</b> (0.000)	<b>0.0001***</b> (0.000)	<b>0.0001***</b> (0.000)	<b>0.0001***</b> (0.000)	<b>0.0001***</b> (0.000)	<b>0.0001***</b> (0.000)
TFCPEP_sh	<b>0.058***</b> (0.010)	<b>0.059***</b> (0.010)	<b>0.059***</b> (0.010)	<b>0.053***</b> (0.011)	<b>0.054***</b> (0.011)	<b>0.054***</b> (0.011)	<b>0.050***</b> (0.012)	<b>0.050***</b> (0.012)	<b>0.050***</b> (0.012)
Lpop	<b>8.475***</b> (0.855)	<b>8.468***</b> (0.858)	<b>8.446***</b> (0.857)	<b>7.462***</b> (0.907)	<b>7.463***</b> (0.908)	<b>7.460***</b> (0.907)	<b>6.736***</b> (0.966)	<b>6.715***</b> (0.964)	<b>6.750***</b> (0.966)
OPENG	-0.003 (0.002)	-0.003 (0.002)	-0.003 (0.002)	-0.002 (0.002)	-0.002 (0.002)	-0.002 (0.002)	0.0002 (0.003)	0.0004 (0.003)	0.0003 (0.003)
<b>Environmental innovation equation</b>	Development of environment-related technologies								
ET	<b>0.005**</b> (0.002)	<b>0.005**</b> (0.002)	<b>0.005**</b> (0.002)	<b>0.005**</b> (0.002)	<b>0.005**</b> (0.002)	<b>0.005**</b> (0.002)	<b>0.007***</b> (0.002)	<b>0.007***</b> (0.002)	<b>0.007***</b> (0.002)
ERGRDB	0.118 (0.106)	0.119 (0.106)	0.119 (0.106)	<b>0.173*</b> (0.106)	<b>0.173*</b> (0.106)	<b>0.176*</b> (0.106)	0.136 (0.100)	0.138 (0.100)	0.138 (0.100)
FDI	-0.002 (0.009)	-0.002 (0.009)	-0.002 (0.009)	-0.007 (0.014)	-0.007 (0.014)	-0.007 (0.014)	-0.001 (0.014)	-0.001 (0.014)	-0.001 (0.014)
TFCPEP_sh	<b>-0.089*</b> (0.051)	<b>-0.089*</b> (0.051)	<b>-0.089*</b> (0.051)	<b>-0.118**</b> (0.053)	<b>-0.118**</b> (0.053)	<b>-0.118**</b> (0.053)	-0.049 (0.058)	-0.049 (0.058)	-0.050 (0.058)
RDPI	1.458 (0.933)	1.464 (0.933)	1.464 (0.933)	1.229 (0.937)	1.237 (0.936)	1.247 (0.936)	1.598 (1.040)	1.606 (1.040)	1.620 (1.040)
Observations	589	589	589	558	558	558	527	527	527
<b>Number of countries</b>	<b>31</b>	<b>31</b>	<b>31</b>	<b>31</b>	<b>31</b>	<b>31</b>	<b>31</b>	<b>31</b>	<b>31</b>

Note: \*, \*\*, and \*\*\* indicates the significance level at 10, 5, and 1% respectively based on the two-tailed test. Standard error estimates are in parentheses. The country-specific effect ( $\eta_i$ ), the time-specific effect ( $\lambda_t$ ), and the constant were included in the regressions of each equation in the model but they are not presented in this table.

Table 3.H.2: Estimations results in the long term, when we use ACO2 instead of CO2

	<i>Lags=4</i>			<i>Lags=5</i>		
	<i>Benchmark model</i>	<i>Alternative specification</i>		<i>Benchmark model</i>	<i>Alternative specification</i>	
		<i>Model A</i>	<i>Model B</i>		<i>Model A</i>	<i>Model B</i>
<b>Economic growth equation</b>	<b>Annual percentage growth rate of GDP per capita</b>					
Change k	-0.016 (0.064)	-0.023 (0.064)	-0.026 (0.064)	0.039 (0.064)	0.036 (0.064)	0.036 (0.064)
Ht-1	-3.524 (6.890)	-3.817 (6.865)	-3.875 (6.856)	-4.277 (6.584)	-4.395 (6.568)	-4.402 (6.572)
Change H	<b>-20.590*</b> (12.358)	<b>-20.863*</b> (12.307)	<b>-21.248*</b> (12.295)	5.109 (11.618)	5.043 (11.587)	5.149 (11.597)
EINNOV	-0.015 (0.040)	-0.017 (0.040)	-0.018 (0.040)	<b>-0.141***</b> (0.039)	<b>-0.142***</b> (0.039)	<b>-0.142***</b> (0.039)
lnY0	1.831 (2.310)	1.902 (2.304)	1.910 (2.302)	2.856 (2.243)	2.885 (2.239)	2.889 (2.240)
TLF	-8.823 (9.405)	-7.722 (9.386)	-7.408 (9.377)	<b>-15.610*</b> (9.463)	<b>-15.119*</b> (9.437)	<b>-15.154*</b> (9.443)
Exp	-0.122 (0.096)	-0.118 (0.096)	-0.117 (0.096)	-0.130 (0.095)	-0.127 (0.095)	-0.127 (0.095)
Tax	0.015 (0.079)	0.013 (0.079)	0.012 (0.079)	-0.003 (0.079)	-0.004 (0.079)	-0.004 (0.079)
Balance	-0.066 (0.052)	-0.062 (0.052)	-0.061 (0.052)	<b>-0.095*</b> (0.055)	<b>-0.093*</b> (0.055)	<b>-0.093*</b> (0.055)
INF	<b>-0.029*</b> (0.016)	<b>-0.029*</b> (0.016)	<b>-0.029*</b> (0.016)	0.018 (0.016)	0.018 (0.016)	0.018 (0.016)
OPENG	0.012 (0.010)	0.013 (0.010)	0.013 (0.010)	0.009 (0.010)	0.009 (0.010)	0.009 (0.010)
<b>Physical investment equation</b>	<b>Real gross fixed capital formation as a percent of GDP</b>					
ET	<b>-0.011***</b> (0.002)	<b>-0.011***</b> (0.002)	<b>-0.009***</b> (0.003)	<b>-0.010***</b> (0.002)	<b>-0.010***</b> (0.002)	<b>-0.011***</b> (0.003)
DEBT		<b>-0.028***</b> (0.010)	0.014 (0.014)		<b>-0.022**</b> (0.010)	<b>-0.027**</b> (0.014)
ET#DEBT			-0.0001 (0.000)			0.00002 (0.000)
Exp	-0.051 (0.096)	-0.024 (0.096)	-0.024 (0.096)	-0.079 (0.102)	-0.062 (0.101)	-0.062 (0.101)
Tax	<b>-0.125*</b> (0.077)	-0.060 (0.080)	-0.055 (0.080)	-0.067 (0.080)	-0.015 (0.084)	-0.017 (0.084)
DCPS	-0.003 (0.004)	<b>-0.009*</b> (0.004)	<b>-0.010**</b> (0.005)	-0.007 (0.004)	<b>-0.012**</b> (0.005)	<b>-0.011**</b> (0.005)
RQ	1.072 (0.816)	0.831 (0.818)	0.732 (0.821)	-0.023 (0.831)	-0.189 (0.829)	-0.174 (0.831)
GNS	<b>0.335***</b> (0.043)	<b>0.297***</b> (0.045)	<b>0.298***</b> (0.045)	<b>0.305***</b> (0.046)	<b>0.276***</b> (0.048)	<b>0.276***</b> (0.048)
<b>Human capital equation</b>	<b>Human-skill index</b>					
LACO2	<b>-0.002**</b> (0.001)	<b>-0.002**</b> (0.001)	<b>-0.002**</b> (0.001)	-0.001 (0.001)	-0.001 (0.001)	-0.001 (0.001)
Exp	0.0002 (0.0005)	0.0003 (0.0005)	0.0002 (0.0005)	-0.0001 (0.0005)	-0.0001 (0.0005)	-0.0001 (0.0005)
FERT	<b>-0.012*</b> (0.006)	<b>-0.012*</b> (0.006)	<b>-0.012*</b> (0.006)	<b>-0.012*</b> (0.006)	<b>-0.012*</b> (0.006)	<b>-0.012*</b> (0.006)
TID	<b>0.094***</b> (0.028)	<b>0.094***</b> (0.028)	<b>0.094***</b> (0.028)	<b>0.061**</b> (0.027)	<b>0.062**</b> (0.027)	<b>0.062**</b> (0.027)

	<i>Lags=4</i>			<i>Lags=5</i>		
	<i>Benchmark model</i>	<i>Alternative specification</i>		<i>Benchmark model</i>	<i>Alternative specification</i>	
		<i>Model A</i>	<i>Model B</i>		<i>Model A</i>	<i>Model B</i>
RQ	0.001 (0.005)	0.001 (0.005)	0.001 (0.005)	-0.00002 (0.005)	-0.00001 (0.005)	-0.00001 (0.005)
<b>ACO2 equation</b>	<b>Logarithm of accumulated carbon dioxide emissions</b>					
ET	<b>-0.001*</b> (0.001)	<b>-0.001*</b> (0.001)	<b>-0.001*</b> (0.0007)	-0.001 (0.0007)	-0.001 (0.0007)	-0.001 (0.0007)
Y	<b>0.0001***</b> (0.000)	<b>0.0001***</b> (0.000)	<b>0.0001***</b> (0.000)	<b>0.0001***</b> (0.000)	<b>0.0001***</b> (0.000)	<b>0.0001***</b> (0.000)
TFCPEP_sh	<b>0.059***</b> (0.013)	<b>0.060***</b> (0.013)	<b>0.059***</b> (0.0138)	<b>0.051***</b> (0.014)	<b>0.051***</b> (0.014)	<b>0.051***</b> (0.014)
Lpop	<b>5.607***</b> (1.065)	<b>5.571***</b> (1.062)	<b>5.590***</b> (1.065)	<b>4.515***</b> (1.176)	<b>4.477***</b> (1.174)	<b>4.478***</b> (1.173)
OPENG	-0.001 (0.003)	-0.001 (0.003)	-0.001 (0.003)	-0.002 (0.003)	-0.002 (0.003)	-0.002 (0.003)
<b>Environmental innovation equation</b>	<b>Development of environment-related technologies</b>					
ET	<b>0.006**</b> (0.003)	<b>0.006**</b> (0.003)	<b>0.006**</b> (0.003)	<b>0.008***</b> (0.003)	<b>0.008***</b> (0.003)	<b>0.008***</b> (0.003)
ERGRDB	0.058 (0.108)	0.058 (0.108)	0.059 (0.108)	0.047 (0.105)	0.048 (0.105)	0.048 (0.105)
FDI	<b>-0.029*</b> (0.017)	<b>-0.029*</b> (0.017)	<b>-0.029*</b> (0.017)	0.003 (0.016)	0.003 (0.016)	0.003 (0.016)
TFCPEP_sh	-0.007 (0.060)	-0.007 (0.060)	-0.007 (0.060)	-0.006 (0.066)	-0.007 (0.066)	-0.007 (0.066)
RDPI	1.101 (1.130)	1.101 (1.130)	1.121 (1.129)	1.142 (1.138)	1.150 (1.137)	1.142 (1.137)
Observations	495	495	495	463	463	463
<b>Number of countries</b>	<b>31</b>	<b>31</b>	<b>31</b>	<b>31</b>	<b>31</b>	<b>31</b>

Note: \*, \*\*, and \*\*\* indicates the significance level at 10, 5, and 1% respectively based on the two-tailed test. Standard error estimates are in parentheses. The country-specific effect ( $\eta_i$ ), the time-specific effect ( $\lambda_t$ ), and the constant were included in the regressions of each equation in the model but they are not presented in this table.

*Table 3.H.3: Estimations results in the long term, when we use ACO2 instead of CO2*

## RÉSUMÉ

Les politiques environnementales, notamment celles recourant aux instruments fiscaux, ont pris une place de plus en plus importante dans un grand nombre de pays durant les trois dernières décennies. Tous les pays de l'OCDE ont introduit des taxes liées à l'environnement et un nombre croissant d'entre eux procèdent à une réforme dite "verte" de leur fiscalité. L'utilisation de la taxe comme un instrument pour la politique environnementale a suscité un large débat parmi les chercheurs sur ses impacts sur la croissance économique, mais sans parvenir à un consensus sur la nature de ces effets. Certains trouvent un effet négatif, alors que d'autres montrent un impact positif. Deux points ont attiré notre attention sur ce sujet. Premièrement, les études empiriques qui vérifient la validité de ces résultats sont très rares. Deuxièmement, la majorité des modèles théoriques qui ont étudié l'effet de la fiscalité environnementale sur la croissance économique supposent que le gouvernement finance ses dépenses uniquement par les taxes et que le budget d'Etat est équilibré à chaque période, évitant ainsi tout fardeau associé au remboursement de la dette publique. Par conséquent, cette thèse a pour objectif d'abord d'explorer empiriquement la nature de la relation entre la fiscalité environnementale et la croissance économique, et si cette relation est sensible au niveau d'autres variables dans l'économie. Ensuite, nous examinons les canaux par lesquels cette taxe peut affecter la croissance économique, et si l'existence et le niveau de la dette publique peuvent modifier cet effet.

**mots-clés :** Fiscalité environnementale, Dette publique, Croissance économique, Imputation multiple, Effets aléatoires corrélés, Modèle à équations simultanées.

## ABSTRACT

Environmental policies, especially those using fiscal instruments, have become more and more important in a large number of countries over the last three decades. All OECD countries have introduced environmentally-related taxes, and a growing number of them are carrying out a so-called "green" reform of their taxation. The use of the tax as an instrument for environmental policy has sparked wide debate among researchers on its impacts on economic growth, but without reaching consensus on the nature of these effects. Some find a negative effect; while others show a positive impact. Two points raised our attention on this subject. First, the empirical studies that verify the validity of these results are very rare. Second, the majority of theoretical models that have studied the effect of environmental taxation on economic growth assume that the government finances its expenditures solely through taxes and that the state budget is balanced each period, thus avoiding any burden associated to repayment of public debt. Therefore, this thesis aims firstly to explore empirically the nature of the relationship between environmental taxation and economic growth, and whether this relationship is sensitive to the level of other variables in the economy. We examine then the channels through which this tax can affect economic growth, and whether the existence and level of public debt can modify this effect.

**keywords:** Environmental taxation, Public debt, Economic growth, Multiple imputation, Correlated random effects, Simultaneous equations model.

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# Thèse de Doctorat

Mahmoud HASSAN

## Fiscalité environnementale, dette publique et croissance économique: une analyse macroéconomique

Environmental taxation, public debt and economic growth: a macroeconomic analysis

### Résumé

Les politiques environnementales, notamment celles recourant aux instruments fiscaux, ont pris une place de plus en plus importante dans un grand nombre de pays durant les trois dernières décennies. Tous les pays de l'OCDE ont introduit des taxes liées à l'environnement et un nombre croissant d'entre eux procèdent à une réforme dite "verte" de leur fiscalité. L'utilisation de la taxe comme un instrument pour la politique environnementale a suscité un large débat parmi les chercheurs sur ses impacts sur la croissance économique, mais sans parvenir à un consensus sur la nature de ces effets. Certains trouvent un effet négatif, alors que d'autres montrent un impact positif. Deux points ont attiré notre attention sur ce sujet. Premièrement, les études empiriques qui vérifient la validité de ces résultats sont très rares. Deuxièmement, la majorité des modèles théoriques qui ont étudié l'effet de la fiscalité environnementale sur la croissance économique supposent que le gouvernement finance ses dépenses uniquement par les taxes et que le budget d'Etat est équilibré à chaque période, évitant ainsi tout fardeau associé au remboursement de la dette publique. Par conséquent, cette thèse a pour objectif d'abord d'explorer empiriquement la nature de la relation entre la fiscalité environnementale et la croissance économique, et si cette relation est sensible au niveau d'autres variables dans l'économie. Ensuite, nous examinons les canaux par lesquels cette taxe peut affecter la croissance économique, et si l'existence et le niveau de la dette publique peuvent modifier cet effet.

### Mots clés

Fiscalité environnementale, Dette publique, Croissance économique, Imputation multiple, Effets aléatoires corrélés, Modèle à équations simultanées.

### Abstract

Environmental policies, especially those using fiscal instruments, have become more and more important in a large number of countries over the last three decades. All OECD countries have introduced environmentally-related taxes, and a growing number of them are carrying out a so-called "green" reform of their taxation. The use of the tax as an instrument for environmental policy has sparked wide debate among researchers on its impacts on economic growth, but without reaching consensus on the nature of these effects. Some find a negative effect; while others show a positive impact. Two points raised our attention on this subject. First, the empirical studies that verify the validity of these results are very rare. Second, the majority of theoretical models that have studied the effect of environmental taxation on economic growth assume that the government finances its expenditures solely through taxes and that the state budget is balanced each period, thus avoiding any burden associated to repayment of public debt. Therefore, this thesis aims firstly to explore empirically the nature of the relationship between environmental taxation and economic growth, and whether this relationship is sensitive to the level of other variables in the economy. We examine then the channels through which this tax can affect economic growth, and whether the existence and level of public debt can modify this effect.

### Key Words

Environmental taxation, Public debt, Economic growth, Multiple imputation, Correlated random effects, Simultaneous equations model.