Interactions spatiales et énergie

Youba Ndiaye

Université Bourgogne Franche-Comté

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Youba NDIAYE

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Interactions spatiales et énergie

Thèse co-dirigée par Julie LE GALLO et Marie-Laure BREUILLE

Composition du jury:

Mme Marie-Laure BREUILLE	Chargée de recherche à l'INRA, Directrice de thèse
Mme Pascale DURAN-VIGNERON	Maîtresse de Conférences, Université de Lorraine, Examinateur
M. Mouez FODHA	Professeur à Paris-Jourdan Sciences Economiques, Rapporteur
Mme Julie LE GALLO	Professeure à AgroSup Dijon, Directrice de thèse
M. Diego LEGROS	Professeur à l'Université Bourgogne Franche-Comté, Président
M. Babacar SENE	Directeur de recherche au CREA, UCAD Dakar, Examinateur
Mme Emmanuelle TAUGOURDEAU	Chargée de Recherche CNRS, ENS Cachan, Rapporteur

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Résumé

Au regard des dégâts environnementaux au cours des dernières années, il est important de mettre en œuvre des politiques environnementales efficaces afin de lutter contre le changement climatique, de préserver la biodiversité, et de réduire les pollutions de l'eau et de l'air. Le secteur énergétique est l'un des principaux contributeurs à la détérioration de l'environnement. Ainsi, afin d'atteindre les objectifs environnementaux, l'établissement de politiques énergétiques efficaces est primordial. A cet effet, il semble indispensable de mener une démarche inclusive et transversale en impliquant l'ensemble des acteurs des différents échelons (locaux, régionaux, nationaux, internationaux,...). Dès lors, l'identification de l'échelon optimal est cruciale dans une optique d'élaboration des politiques énergétiques efficaces. La thèse s'attache précisément à éclairer les enjeux liés à la fiscalité énergétique. Ainsi, l'objectif principal de cette thèse est d'analyser la nature des interactions environnementales, qu'elles soient entre régions ou Etats, en termes de fiscalité ou de dépenses environnementales. Les contributions de cette thèse sont à la fois théorique et empirique.

D'un point de vue empirique, cette thèse s'est d'abord focalisée sur l'étude de la fiscalité énergétique sous l'angle des interactions spatiales. En particulier, le chapitre 1 teste la présence des interactions spatiales des départements français *via* la vignette automobile. Ce chapitre fournit une analyse empirique de la réaction de la politique fiscale d'un département français suite à un changement de la politique fiscale de ces voisins. Tout d'abord, en utilisant une approche économétrique spatiale en panel, les résultats montrent l'existence d'une dépendance spatiale positive, suggérant l'existence d'un comportement mimétique des départements français lors de la détermination des taux de la vignette automobile. Ensuite, ce chapitre met également en évidence une relation entre les impôts directs locaux et ceux indirects locaux. En particulier, les résultats des estimations montrent que le taux de la taxe professionnelle (resp. la taxe sur le foncier bâti) et la vignette automobile sont des substituts alors que le taux de la taxe d'habitation (resp. la taxe sur le foncier non bâti) sont des compléments à la vignette automobile. Enfin, les résultats montrent que les départements avec des populations plus grandes, plus jeunes et plus âgées fixent des montants plus élevés de la vignette automobile.

D'un point de vue théorique, le but du chapitre 2 est d'analyser les interactions fiscales entre des gouvernements à deux niveaux, composés de plusieurs gouvernements régionaux et d'un gouvernement fédéral. Tous peuvent taxer deux bases d'imposition, c'est-à-dire le capital et une ressource énergétique, qui sont interdépendantes. Nous déterminons grâce à la formalisation théorique les implications en termes de distorsions fiscales de l'architecture fiscale dans le cadre d'une politique énergétique. En particulier, en recourant au jeu de Nash, nos résultats montrent d'abord que le compromis fédéral entre la taxation du capital et la taxation de l'énergie ne dépend que de l'offre exogène relative en énergie et en capital. Ensuite, le compromis entre la taxation du capital et celle de l'énergie est beaucoup plus complexe, car il dépend également de la comparaison des effets de distorsion de ces taxes sur le bien public régional et la qualité de l'environnement, ainsi que sur l'interdépendance des deux taxes. Enfin, nous trouvons également une substituabilité entre les taxes fédérales et régionales, quelle que soit l'interdépendance de ces deux taxes, ce qui implique que le gouvernement fédéral augmente un taux d'imposition donné en réponse à la diminution de

l'un des deux taux d'impôt régionaux.

Enfin, à travers le chapitre 3, nous testons d'un point de vue empirique l'existence d'une interdépendance spatiale entre les pays de l'OCDE *via* les dépenses environnementales. À cette fin, nous recourons aux données de 30 pays de l'OCDE pour la période 1994-2014 et une large gamme de variables de contrôle économiques et politiques. Les résultats montrent l'existence d'une interdépendance spatiale positive dans les dépenses environnementales. En outre, en guise d'analyse complémentaire, nous testons les interactions spatiales sur le budget R&D en matière d'énergie et d'émissions de CO2, et pour ces deux problématiques, nous trouvons des preuves de l'existence des effets positifs d'interaction spatiale. En résumé, les résultats de ce chapitre confirment l'hypothèse selon laquelle les pays de l'OCDE agissent de manière interdépendante entre voisins lorsqu'ils formulent des choix politiques liés aux dépenses environnementales, à la R&D dans le secteur de l'énergie et à la lutte contre les émissions de CO2.

Abstract

In the light of environmental damage in recent years, it is important to implement effective environmental policies to combat climate change, preserve biodiversity, and reduce water and air pollution. The energy sector is one of the main contributors to the deterioration of the environment. Thus, in order to achieve environmental objectives, establishing effective energy policies is essential. To this end, it seems essential to carry out an inclusive and transversal approach by involving all actors at different levels (local, regional, national, international, etc.). Therefore, identifying the optimal tier is crucial for effective energy policy development. The thesis focuses on clarifying the issues related to energy taxation. Thus, the main objective of this thesis is to analyze the nature of environmental interactions, between regions or states, in terms of taxation or environmental expenses. The contributions of this thesis are both theoretical and empirical.

From an empirical point of view, this thesis first focuses on the study of energy taxation from the perspective of spatial interactions. In particular, Chapter 1 tests the presence of spatial interactions of French departments *via* the road tax sticker. This chapter provides an empirical analysis of the reaction of the tax policy of a French department following a change in the tax policy of these neighbors. Firstly, by using a spatial econometric panel approach, the results show evidence of spatial dependence, suggesting the existence of a mimetic behavior of French departments when determining the rates of the road tax sticker. Secondly, this chapter also highlights a relationship between local direct taxes and indirect local taxes. In particular, the estimation results show that the rate of the business tax (or the tax on undeveloped land) and the road tax sticker are substitutes, whereas the rate of the residential tax (or the tax on developed land) are complements to the road tax sticker. Finally, the results show that departments with larger, younger and older populations are setting higher amounts of the road tax sticker.

From a theoretical point of view, the purpose of Chapter 2 is to analyze the tax interactions between two-tier governments, composed of several regional governments and one federal government. Everyone can tax two tax bases, that are, capital and an energy resource, which are interdependent. Through theoretical formalization, we determine the implications in terms of tax distortions of tax architecture in the context of an energy policy. In particular, using the Nash game, our results show first that the federal trade-off between capital taxation and energy taxation depends only on the relative exogenous supply of energy and capital. Secondly, the trade-off between capital and energy taxation is much more complex, as it also depends on comparing the distorting effects of these taxes on the regional public good and the quality of the environment, as well as on the interdependence of the two taxes. Finally, we also find a substitutability between federal and regional taxes, regardless of the interdependence of these two taxes, which implies that the federal government increases a given tax rate in response to the decrease of one of the two regional tax rates.

Finally, in Chapter 3, we empirically test the existence of spatial interdependence among OECD countries through environmental spending. To this end, we use data from 30 OECD countries for the period 1994-2014 and a wide range of economic and political control variables. The results show a positive spatial interdependence in environmental spending. In addition, as a complementary analysis, we test the spatial interactions on the R&D budget for energy and CO2 emissions, and for these two issues, we find evidence of the existence of positive effect of spatial interactions. In summary, the results of this chapter support the hypothesis that OECD countries act interdependently with neighbors when formulating policy choices related to environmental spending, R&D in the energy sector and the fight against CO2 emissions.

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Introduction générale

0.1 Enjeux environnementaux et outils de régulation:

Les gouvernements à travers la planète font face à des enjeux environnementaux multiples tels que le changement climatique, la préservation de la nature et la biodiversité, l'amélioration de la santé humaine et l'utilisation optimale des ressources naturelles. Si certains de ces enjeux, à l'instar de la gestion des déchets, peuvent s'envisager comme étant essentiellement locaux, nombre d'entre eux revêtent un caractère plus global comme la pollution atmosphérique, qui a entrainé plus de 6,5 millions de morts à travers le monde (IEA, 2015).

Le secteur énergétique est l'un des principaux contributeurs à la détérioration de l'environnement. De fait, en 2013, les émissions de CO2 liées à l'énergie ont atteint un record de 32,2 milliards de tonnes, ce qui représente environ 75% des émissions mondiales de gaz à effet de serre (OECD, 2015). Plusieurs études du Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC) montrent que l'utilisation des énergies fossiles (charbon, pétrole, gaz naturel) représente environ 81% de la consommation totale d'énergie à l'échelle mondiale (IEA, 2009). A l'échelle de la France, l'utilisation annuelle de l'énergie hors biomasse représente en moyenne 69% des émissions de GES et près de 95% des émissions de CO2 sur tout le territoire (CITEPA, 2010). Les trois principaux secteurs responsables de ces dégâts environnementaux sont le bâtiment, les transports et l'aménagement-urbanisme. Selon l'Agence Internationale de l'Energie (AIE), le secteur du transport est celui qui représente la plus grande part de la consommation finale de l'énergie, avec 34% en 2014 (IEA, 2017), suivi du secteur de l'industrie manufacturière avec 27% et du secteur résidentiel à hauteur de 19%. A l'échelle française, le secteur du transport représentait 33% des émissions de CO2 en 2008, dont 23% pour le seul transport routier (CITEPA, 2010).

Pour faire face à ces défis environnementaux, différentes mesures internationales ont été prises, et ce à différentes échelles. A l'échelle mondiale, le sommet de la COP21 en 2015 à Paris a permis de trouver un premier accord universel pour le climat, ratifié par 196 délégations et entré en vigueur le 4 novembre 2016, avec pour objectif de maintenir l'augmentation de la température globale de la planète en dessous des 2 degrés. Dans le cadre communautaire, l'Union Européenne s'inscrit dans une logique de transition énerg étique en s'orientant vers une économie "basse carbone", à travers le *package* Climat et Energie adopté en 2010 qui a fixé des objectifs drastiques en matière de politique énergétique (Directive/29/CE, 2009). En effet, les principaux objectifs de cet accord sont : (1) de réduire les gaz à effet de serre d'au moins 20% d'ici 2020 par rapport à leur niveau de 1990 ; (2) d'atteindre 20% des énergies d'origine renouvelable ; (3) d'atteindre 10% de la consommation de carburant d'origine renouvelable pour le transport. Cependant, les Etats membres demeurent souverains en matière de ressources énergétiques et de moyens pour atteindre les objectifs fixés par l'Europe tout en prenant en compte le fait que les ressources énergétiques sont de diverses formes et dispersées dans l'espace. Leur exploitation modifie alors la répartition géographique des potentiels énergétiques. Dans le contexte français, à travers la loi de programmation relative à la mise en oeuvre du Grenelle de l'environnement, i.e. la loi Grenelle 1, les autorités politiques ont pris des mesures de lutte contre le changement climatique : d'une part, la réduction des émissions de gaz à effet de serre des secteurs des transports et de l'énergie, et d'autre part, la baisse de la consommation d'énergie des bâtiments. Le secteur de l'énergie en général et celui du transport en particulier sont donc bien au cœur des dispositifs mis en place, et ce autant à l'échelle locale, nationale, qu'internationale.

Plusieurs raisons permettent de justifier la mise en place d'une politique énergétique. Une première raison est liée à l'existence d'externalités environnementales telles que la pollution. Ensuite, la question énergétique peut être liée aux problématiques de sécurité nationale. En effet, les catastrophes naturelles ou d'autres formes de troubles politiques peuvent fragiliser le secteur de l'énergie et impacter l'accès à l'énergie. De plus, étant donné la particularité du secteur de l'énergie, les pouvoirs publics doivent réguler ce secteur afin de corriger les défaillances du marché. Enfin, l'existence de rentes d'expropriation est souvent source de tensions entre différents échelons de gouvernements. En effet, dans certains pays, les rentes d'exploitations sont gérées par les autorités locales, ce qui peut générer des disparités fiscales importantes entre les collectivités locales. Ces disparités peuvent alors se matérialiser par des écarts considérables en termes de fourniture de biens publics locaux.

Afin d'atteindre les objectifs environnementaux, il semble ainsi indispensable de mener une démarche inclusive et transversale en impliquant l'ensemble des acteurs des différents échelons (locaux, régionaux, nationaux, internationaux,...). Parmi les différents leviers pouvant être actionnés, les acteurs politiques peuvent tout d'abord avoir recours à des mesures réglementaires telles que les quotas et les permis. Cependant, ces mesures visent à contraindre le comportement des agents et n'incitent pas nécessairement à des comportements plus écologiques. Les pouvoirs publics peuvent également adopter des instruments économiques reposant sur une approche incitative destinée à favoriser les comportements vertueux et qui sont plus enclins à assurer une efficience globale des politiques environnementales. D'une part, les instruments économiques peuvent combler les lacunes des mécanismes de marché *via* un ajustement afin d'internaliser les externalités. D'autre part, la mise en oeuvre administrative de ces instruments est beaucoup plus aisée. En pratique cependant, ces instruments économiques servent souvent à compléter les mesures réglementaires et non à les remplacer.

La fiscalité environnementale appartient à la catégorie des instruments économiques. La fiscalité environnementale peut être définie comme l'ensemble des mécanismes financiers incitant au changement de comportements des agents économiques (consommateurs, producteurs) *via* différentes mesures. Ces mesures peuvent prendre la forme de taxes, de dispositifs de tarification ou encore de subventions. La fiscalité environnementale incite les agents à adopter des comportements

[5] Source: Julien VANDEBURIE. http://www.etopia.be/spip.php?article3251

plus vertueux vis-à-vis de l'environnement et vise à internaliser des externalités négatives (pollution de l'air ou des sols, maladies environnementales, etc) selon le principe du "pollueur payeur".

Un argument supplémentaire de la fiscalité environnementale est largement explorée à travers la littérature sur la notion de double dividende. En effet, une critique récurrente des politiques environnementales porte sur les effets éventuellement néfastes des mesures environnementales (réglementaires ou économiques) sur la croissance, sur l'emploi, ... A cet égard, nombreux auteurs (Bovenberg, 1999; Goulder, 1995; Jorgenson et al., 2013; Sancho, 2010) ont montré les avantages de la fiscalité environnementale à travers la possibilité de l'existence d'un double dividende. L'intuition qui sous-tend cette notion est fondée sur l'idée selon laquelle il est possible d'améliorer la qualité de l'environnement tout en réduisant les côuts associés au systéme fiscal en général. En d'autres termes, les recettes environnementales pourraient permettre de réduire les distorsions existantes dans le systéme fiscal déja en place, et in fine générées un bénéfice purement économique en termes de croissance, d'emploi ou plus généralement de bien-être économique Chiroleu-Assouline (2007). La littérature montre deux issues en lien avec cette notion de double dividende. D'une part, il y a la version faible indique qu'il est moins coûteux d'utiliser les recettes fiscales environnementales pour réduire un impôt distorsion existant plutôt que de redistribuer ces recettes en transferts forfaitaires Chiroleu-Assouline (2007); Goulder et al. (1999). D'autre part, la forme forte se produit si la taxe environnementale est moins distordante que les autres taxes distordantes existantes. En d'autres termes la version forte du double dividende survient dés lors que la taxe environnementale induit un coût en bien-être plus faible qu'une taxe distordante de même rendement.

Au regard de l'étendu et de la diversité des dégâts environnementaux (pollution locale, déchets, dégradation de la biodiversité, effet de serre), une complémentarité entre instruments de régulation environnementale a plusieurs avantages. A cet effet, il y a une nouvelle littérature qui émerge, montrant que la combinaison de taxes sur le carbone et de subventions de recherche pour stimuler l'innovation et le développement de technologies propres peut être socialement optimale Garon and Paquet (2017). D'un point de vue pratique, en guise d'illustration, il ya eu au Royaume Uni, la loi du "Climate change levy" qui combine plusieurs instruments tels que la taxe sur la consommation intermédiaire d'énergie, le marché des permis, afin de lutter contre le changement climatique.

Parallèlement, les autorités publiques peuvent engager des dépenses environnementales, à savoir des ressources consacrées à toutes les activités et actions qui ont pour principal objectif la prévention, la réduction et l'élimination de la pollution et de toute autre forme de dégradation de l'environnement[1]. Les dépenses environnementales visent à élaborer des politiques environnementales plus efficaces, notamment en identifiant les synergies entre les instruments économiques et environnementaux. En outre, avec la transition énergétique, les dépenses en R&D constituent également un levier important dans la lutte contre le changement climatique. En effet, les investissements dans le domaine résidentiel avec des bâ timents à faible intensité énergétique, dans le domaine du transport avec l'étendue du parc des véhicules électriques sont des exemples de mesures d'amélioration de la qualité environnementale dans plusieurs pays développés. Dans le cadre de la stratégie européenne du triple 20, l'objectif de la Commission Européenne en matière de R&D est d'atteindre 3% du PIB, dont 2/3 financés par le secteur public (Montmartin and Herrera, 2015), alors qu'actuellement les investissements en R&D de l'Union Européenne s'élèvent à 2.3% du PIB dont 55% financés par le secteur privé (Eurostat).

0.2 Nature des interactions spatiales:

La mobilisation de ces différents leviers génère des interactions spatiales entre les gouvernements, i.e., une relation d'interdépendance des gouvernements qui sont plus ou moins proches géographiquement. Ainsi, au-delà de la dimension spatiale des enjeux environnementaux, avec par exemple une diffusion géographique des coûts externes variant suivant les conditions géographiques Nicolaisen et al. (1991), la dimension spatiale des interactions entre politiques publiques environnementales est cruciale, quoique très peu étudiée jusqu'à présent.D'un point de vue théorique, la littérature traditionnelle en économie publique a largement explicité les effets externes que peuvent engendrer les décisions budgétaires, à partir des travaux précurseurs de Musgrave et al. (1959); Oates Wallace (1972); Tiebout (1956). En l'absence de coordination, les pays ont tendance à fixer des taux de taxes ou des niveaux des dépenses sous-optimaux au sens où ces derniers n'internalisent pas les externalités.

Du point de vue de la fiscalité, deux principales raisons sont avancées pour expliquer l'existence d'interactions spatiales entre gouvernements. La première est la concurrence fiscale, avec les travaux précurseurs de Wilson (1986),Wilson (1999), Zodrow and Mieszkowski (1986). Pour attirer une base fiscale mobile, les gouvernements se font concurrence et fixent un taux à l'équilibre inefficacement bas par rapport au taux qui serait choisi par un planificateur bienveillant internalisant les externalities. On parle dans ce cas de "race to the bottom". La seconde est la concurrence par comparaison, qui a été formalisée par Shleifer (1985), et Salmon (1987). L'interaction dans ce cas provient du fait que la probabilité de réélection d'un gouvernement dépend non seulement de ses propres décisions mais également des décisions budgétaires des gouvernements voisins. Les nombreuses études empiriques traitant de l'interdépendance entre les décisions fiscalesAgrawal (2013); Allers and Elhorst (2005); Dubois et al. (2005); Edmark and Ågren (2008); Eugster et al. (2013); Feld et al. (2002); Jayet et al. (2002); Leprince et al. (2005); Lyytikäinen (2012); Reback (2007); Revelli (2001) concluent généralement à une dépendance spatiale positive.

Du point de vue des dépenses, trois principales raisons sont avancées pour justifier l'existence d'interactions spatiales. Premièrement, un pays peut concurrencer ses voisins afin d'attirer de la main d'oeuvre qualifiée et des firmes (Case et al. (1993); Revelli (2003); Lundberg (2006)). En matière environnementale, les pays peuvent adopter des comportements mimétiques ou stratégiques en déterminant leurs efforts environnementaux en fonction de leurs voisins. La localisation des entreprises oriente souvent, et de façon importante, les décisions des pouvoirs publics dans la planification des dépenses en lien avec l'environnement. A titre d'exemple, des pays qui imposent des normes environnementales très strictes en termes d'investissements peuvent inciter certaines entreprises à se délocaliser pour s'installer dans des pays où les normes environnementales sont moins rigoureuses. Deuxièmement, *via* la concurrence par comparaison, un gouvernement peut concurrencer ses voisins en améliorant sa croissance et son développement à des fins électorales (Chen et al. (2005); Caldeira (2012)). Les citoyens soucieux de l'avenir de leur planète peuvent exercer des pressions sur leurs gouvernements en faisant dépendre leurs votes des moyens engagés pour répondre aux enjeux environnementaux. Enfin, l'existence d'effets de débordement liées aux dépenses ((Ollé (2003); Freret et al. (2005))) est la dernière source d'interactions. Les dépenses en infrastructures vertes ou pour lutter contre les émissions de CO2 bénéficient souvent aux habitants des pays voisins.

La littérature sur les interactions stratégiques en lien avec l'environnement s'oriente davantage sur l'impact des mesures de régulation environnementale entre les gouvernements décentralisés. Cette littérature se focalise sur l'idée selon laquelle la régulation environnementale d'un pays dépend de celle de ses voisins (Fredriksson et al., 2004; Fredriksson and Millimet, 2002; Konisky and Woods, 2012; Levinson, 2003). En guise d'illustration, Fredriksson and Millimet (2002) testent l'existence d'interactions stratégiques des Etats aux Etats Unis, dans la mise en œuvre de leurs politiques environnementales sur la période de 1977 à 1994. Leurs résultats suggèrent qu'il existe une association positive entre les Etats dans la plannification de leurs politiques environnementales. Dans le même sillage, Woods (2006) étudie l'exécution d'une régulation environnementale dans le secteur de l'industrie minière dans 33 Etats des Etats Unis sur la période de 1987 à 1999. Son résultat montre l'existence d'interactions stratégiques entre les états impliquant que l'adoption de la mesure environnementale d'un état dépend des mesures environnementales antérieures de ces voisins.

Alors que les interactions *via* la fiscalité ont été largement étudiées (Leprince et al., 2005; Revelli, 2001) et *via* les dépenses en général (Bartolini and Santolini, 2012; Binet et al., 2010; Solé-Ollé, 2006), rares sont celles qui concernent la fiscalité énergétique, les dépenses environnementales ou de R&D du secteur de l'énergie. La thèse s'attache précisément à éclairer les enjeux liés à la fiscalité énergétique.

0.3 Les interactions environnementales entre gouvernements

Les questions soulevées par ce champ de recherche en pleine émergence qu'est le fédéralisme environnemental sont nombreuses. Quelle est l'architecture territoriale optimale pour une politique fiscale énergétique efficace? Quel échelon de gouvernement devrait taxer quelles ressources énergétiques afin de limiter les distorsions fiscales, tout en assurant une utilisation durable des ressources énergétiques? Quelle est la nature des interactions entre gouvernements dans la mise en oeuvre de leurs politiques environnementales et en particulier énergétiques? Agissent-ils par mimétisme? Ou profitent-ils de l'implication active de leurs voisins dans la protection de l'environnement pour se désengager?

Cette thèse, qui se décompose en trois chapitres, analyse la nature des interactions environnementales, qu'elles soient entre régions ou Etats, en termes de fiscalité ou de dépenses et fournit des éléments de réponse à ces questions. La démarche adoptée est à la fois théorique et empirique.

0.3.1 Interactions entre gouvernements régionaux à travers le cas de la vignette automobile

La majeure partie de la consommation énergétique et de la pollution étant imputable au secteur du transport, la mise en oeuvre d'instruments de régulation dans ce secteur représente un enjeu important en termes de protection de l'environnement. Le premier chapitre de cette thèse se focalise sur la fiscalité locale du secteur du transport routier, et plus précisément sur la vignette automobile prélevée en France par les départements à partir de 1984. Instaurée en 1956 par l'Etat français afin de financer les retraites, sa gestion a été décentralisée aux départements lors de la première phase de décentalisation. Les départements pouvaient, de 1984 à 2000, choisir librement le montant de la vignette payé par les particuliers sur les véhicules en circulation. Ce montant était déterminé en fonction de l'âge et de la puissance fiscale du véhicule. De notables comportements de différenciation ont été observés entre départements. Le département de la Marne, dans les années 90, avait par exemple choisi de pratiquer des montants très faibles de la vignette afin d'attirer plus de véhicules à d'immatriculer dans ledit département, avec pour conséquence un doublement des revenus issus de la vignette sur la période de 1996 à 1998. Si la vignette automobile française n'avait pas un objectif environnemental explicite, cette vignette est néanmoins utilisée actuellement dans de nombreux pays européens comme un moyen de lutter contre la pollution de l'air. Par ailleurs, le ministre de l'écologie François de Rugy a annoncé le 23/09/2018 que le gouvernement français travaille sur le retour d'une vignette pour les transporteurs routiers (principalement les poids lourds). Ceci donne ainsi un regain d'intérêt à l'analyse de la fiscalité écologique française.

En testant l'existence d'interactions spatiales entre les départements français dans le choix de fixation du montant de la vignette, et en identifiant les principaux déterminants du montant de la vignette fixée par les départements, ce chapitre permet de mettre à jour l'existence de potentielles distorsions fiscales liées à une concurrence fiscale horizontale, et ainsi de porter cet élément à la connaissance des pouvoirs publics avant qu'ils ne décident des modalités de prélèvement d'une nouvelle vignette, dans un contexte de réflexion sur la fiscalité locale. Si des distorsions fiscales trop importantes existent lorsque la vignette est prélevée par les départements, le législateur peut en effet préférer un prélèvement au niveau de l'Etat.

Pour tester l'existence d'interactions fiscales entre départements *via* la vignette, une première génération de travaux se focalise sur les modèles de l'économétrie spatiale. Les principaux résultats de cette littérature ont tendance à confirmer l'existence d'une dépendance spatiale positive (Allers and Elhorst, 2005; Dubois et al., 2005; Edmark and Ågren, 2008; Feld et al., 2002; Jayet et al., 2002; Leprince et al., 2005; Revelli, 2001). Cependant, il existe une seconde génération de travaux empiriques qui est fondée sur l'idée selon laquelle il est difficile d'identifier la source des interactions spatiales entre localités (Agrawal, 2013; Eugster et al., 2013; Lyytikäinen, 2012; Reback, 2007). Cette seconde génération se focalise sur des expériences naturelles afin de différencier les différentes sources des interactions spatiales. Notre chapitre 1 s'oriente davantage vers la première génération de travaux empiriques sur les interactions spatiales. En effet, le but de ce chapitre n'est pas d'identifier la source des interactions spatiales *via* la vignette automobile mais plutôt de tester l'existence de ces interactions. La principale nouveauté de ce chapitre est de focaliser l'analyse des interactions spatiales entre départements à travers une taxe indirecte sur les véhicules, à savoir la vignette automobile. Nous recourons aux modèles spatiaux autoregressifs (modèles SAR, *Spa-*

tial Autoregressive Model) pour tester comment un département modifie sa vignette suite à une modification du montant de la vignette de ses voisins Brueckner (2003); Brueckner and Saavedra (2001); Ollé (2003); Revelli (2001, 2003), que nous estimons à partir d'une base de données en panel originale regroupant les 96 départements français sur la période de 1984 à 2000. Cette étude apporte une contribution importante sur les déterminants de la vignette automobile en intégrant l'espace dans l'analyse des politiques publiques locales, en l'occurrence celles des départements français. Elle permet également de quantifier la relation entre la fiscalité directe locale (à savoir les 4 principales taxes que sont la taxe professionnelle, la taxe d'habitation, la taxe sur le foncier non bâti et celle sur le fonction bâti) et la fiscalité indirecte locale.

0.3.2 La fiscalité énergétique, une approche théorique

Le chapitre 1 pose donc en creux la question de l'affectation de la fiscalité énergétique à un échelon de gouvernement, qui est une question à laquelle nous répondons de manière théorique dans le deuxième chapitre. Nous déterminons grâce à la formalisation théorique les implications en termes de distorsions fiscales de l'architecture fiscale dans le cadre d'une politique énergétique. Rares sont les études qui se focalisent sur l'analyse des interactions entre gouvernements *via* les taxes environnementales. Néanmoins, Alexeev et al. (2016) ont apporté une contribution non négligeable sur les implications du partage des rentes environnementales entre consommations privée et publique. Leurs résultats montrent que le bien-être juridictionnel tend à augmenter au fur et à mesure que les rentes environnementales sont affectées à la consommation publique. Ils montrent également que les décisions des juridictions décentralisées sont efficientes dès lors que les mesures de politiques environnementales et fiscales sont prises à leur "benchmark". Dans le même ordre d'idée, Kim and Wilson (1997) explore la célèbre notion de la "course vers le bas" en montrant dans quelle condition la concurrence sur la mobilité du capital peut conduire à une fourniture non-optimal des biens publics à l'équilibre.

Ce chapitre apporte deux contributions à la littérature existante. D'une part, nous nous plaçons dans un cadre à deux échelons, avec un gouvernement central et des gouvernements locaux, à la Keen and Kotsogiannis (2002). Alternativement, le modèle peut être interprété à l'échelle d'une Union Economique composée de nombreux pays. Le partage d'une même base fiscale par deux échelons génère donc des externalités fiscales verticales, en plus des externalités fiscales horizontales, dans un contexte de dégradation de l'environnement. Il existe une relation inverse entre la qualité de l'environnement et la demande d'énergie, l'augmentation de la consommation de l'énergie détériorant l'environnement. Ceci traduit un arbitrage entre protection de l'environnement et consommation de l'énergie. D'autre part, les deux échelons peuvent taxer deux bases fiscales, à savoir le capital et l'énergie, qui sont potentiellement interdépendantes. Les interactions fiscales s'exercent ainsi également indirectement entre bases fiscales, à l'instar de Breuillé and Duran-Vigneron (2018). En recourant au modèle de concurrence symétrique, nous déterminons dans un premier temps le comportement des juridictions à travers un jeu à la Nash. En d'autres termes, le gouvernement central et les gouvernements locaux choisissent simultanément leurs taux de taxes

[5] Ce chapitre a fait l'objet d'une publication: Ndiaye (2018)

sur le capital et sur l'énergie, en prenant comme données les stratégies des autres joueurs.

0.3.3 Les dépenses environnementales, les dépenses en R&D du secteur du l'énergie et émissions de CO2

Les interactions budgétaires entre gouvernements peuvent également transiter par les dépenses. D'un point de vue empirique, rares sont les articles qui analysent les interactions spatiales *via* les dépenses environnementales ((Deng et al. (2012), Ercolano and Romano (2017) Ermini and Santolini (2010)). A titre d'exemple, Deng et al. (2012) examinent les facteurs déterminant les dépenses publiques environnementales dans 249 provinces chinoises. Leurs résultats montrent que les gouvernements provinciaux adoptent des comportements stratégiques dans la mise en œuvre de leurs politiques budgétaires liées à la protection de l'environnement. Les provinces ont tendance à diminuer leurs dépenses environnementales en réponse à une augmentation de celles des provinces voisines. Le chapitre 3 a pour objectif de combler ce manque en analysant les politiques sur les dépenses environnementales à la fois à l'échelle des pays et sous l'angle des interactions spatiales. Ainsi, l'objectif de ce chapitre est de tester l'existence d'interaction spatiales entre les pays de l'OCDE transitant par les dépenses environnementales. Afin d'atteindre cet objectif, nous avons construit une base de données annuelles originale regroupant 30 pays de l'OCDE sur la période 1994-2014 reflétant les caractéristiques économiques, sociales et environnementales des pays. Les contributions de ce chapitre 3 peuvent être résumées en trois points principaux. Tout d'abord, en recourant aux outils de l'économétrie spatiale, ce travail permet de faire une analyse des comportements stratégiques des pays *via* les dépenses environnementales. Ensuite, elle permet de tirer des leçons sur les effets néfastes des comportements mimétiques des pays au détriment d'une politique environnementale axée principalement sur les enjeux environnementaux (restauration de la biodiversité, amélioration de la qualité de l'air, diminution des émissions de CO2, ...). Enfin, ce travail permet aux pouvoirs publics d'intégrer ces interactions spatiales des dépenses environnementales dans l'analyse des politiques publiques afin d'identifier des leviers propices à un développement durable. Une analyse poussée des déterminants des comportements des pays est de fait importante dans les choix d'investissements des gouvernements en matière de dépenses environnementales. Concernant l'étude sur les interactions *via* les dépenses en R&D de l'énergie, cette étude contribue à la littérature existante sur les déterminants des dépenses gouvernementales en R&D en considérant le role des interactions stratégiques entre les pays de l'OCDE comme étant un facteur explicatif de la concurrence.

En guise d'analyse complémentaire, nous testons également l'existence de dépendance spatiale dans les dépenses R&D du secteur de l'énergie et les émissions de CO2. D'une part, l'intérêt de tester l'hypothèse d'interactions spatiales dans le secteur de l'énergie permet d'évaluer la portée de nos résultats sur les dépenses environnementales en termes de généralité versus spécialité. En particulier, nous cherchons à tester si nos résultats sur les dépenses environnementales sont généralisables ou sont plutôt spécifiques à certains secteurs. En outre, cette analyse sur les R&D dans le secteur de l'énergie permet de fournir aux pouvoirs publics des informations utiles dans leur décisions d'investissements en R&D lièes à l'énergie. D'autre part, il est intéressant d'effectuer une investigation supplémentaire sur les émissions d'un point de vue spatial afin de d'explorer les comportements des pays dans leur politique de gestion des émissions de CO2.

0.4 Organisation de la thèse

Cette thèse s'organise autour de 3 chapitres.

Le chapitre 1 étudie la fiscalité énergétique en examinant les interactions spatiales des départements français *via* la vignette automobile.

Le chapitre 2 analyse d'un point de vue théorique les interactions fiscales entre deux échelons de gouvernements qui taxent deux bases interdépendantes.

Le chapitre 3 étudie les comportements des pays de l'OCDE à travers les dépenses environnementales.

Dans la conclusion, nous présentons les résultats et leurs implications, puis les limites et enfin, nous proposons quelques perspectives d'enrichissement de ce travail.

Chapter 1

Road tax interactions among local governments:

A spatial panel data analysis of the French case over the period 1984-2000.

Abstract

This article contributes to the literature on local tax interactions. Its novelty lies in its focus on the interactions of local governments via an indirect local tax on vehicles such as the road tax sticker and its analysis of interactions between direct and indirect local taxation. The main purpose of this paper is to provide an empirical analysis of the reaction of road tax policy in a given French "department" to changes in road tax policy in other "departments". The analysis uses a novel panel dataset covering the 96 French metropolitan "departments" for the period from 1984 to 2000. Firstly, the results confirm the presence of significant spatial interactions between French "departments" due to the road tax sticker, i.e, French departments tend to implement road tax sticker rates that are similar to those of their neighbors. Secondly, the estimation results also show that the business tax rate and/or the property tax rate on developed land are complements to the road tax sticker whereas the residence tax rate and/or the property tax rate on undeveloped land are substitutes to the road tax instrument. Thirdly, estimation results show that the mobility of the road tax base cannot be rejected. Finally, I find that "departments" with a larger, younger and older population set higher rates for the road tax sticker. The results are robust regarding alternative weight matrices.
Keywords: road tax sticker; mimicking behavior; maximum likelihood; spatial econometrics; panel. **JEL classification**: C33, H7.

1.1 Introduction

The vehicle taxation system is basically comprised by three tax instruments: a vehicle acquisition tax (VAT, Registration tax, and Registration fee), a tax on vehicle ownership (the road tax sticker) and a tax on monitoring (excise duty on fuels + VAT, tolls on roads and bridges). This paper focuses on the second type of tax, namely the road tax sticker. The latter is a form of road pricing imposed on vehicles, usually in addition to compulsory road tax. The road tax sticker is currently used in several European countries such as Denmark, Sweden, Italy, Austria, Finland, the Netherlands, Czech Republic and, more recently, in Germany. In these countries this road tax is levied at the upper-tier (national level). In France, the road tax sticker was introduced in 1956 at the national level and then decentralized in 1984 to the "department" level (middle-tier), until its abolition in 2000 for private cars. The amount paid for the road tax sticker depended on the age of the vehicle, its engine horsepower, and, since 1984, the "department" in which the car was registered. The main purpose of this study is to test the existence of fiscal interactions between French departments via the road tax sticker.

Fiscal interaction between governments has been a quite widespread theme in public finance and regional science, which has improved our understanding of the relationships between governments at the same level (horizontal externalities) and between different government tiers (vertical externalities). The theoretical literature on fiscal interaction between local governments has identified several potential sources of interdependence in decision-making on taxation. On the one hand, in models of tax competition (Wilson (1986), Zodrow and Mieszkowski (1986)), the fiscal choices of a jurisdiction depend on the choices of neighboring locations (response functions). On the other hand, in yardstick competition models (introduced by Shleifer (1985) and Salmon (1987) and further developed by Besley and Case (1995), a government aligns its fiscal policy with the policies of its neighbors to ensure reelection. Note that the aim of this paper is not to disentangle between these sources of interdependence.

Regarding the empirical literature on fiscal interactions, two main generations can be highlighted. Earlier empirical works focused on spatial models (spatial lag or spatial error models) to address the issue of spatial interactions between jurisdictions, and more specifically the existence of mimicking behavior between jurisdictions in their local tax choices. A common characteristic of these numerous case studies is the presence of positive spatial dependence[4]. For instance, Revelli (2001) tested for mimicry in setting local tax, by using a panel data set of English non-metropolitan districts in the 1980s – when property tax rate variability across districts was highest. His results confirmed the presence of significant and wide horizontal interaction between UK districts. As for France, Leprince et al. (2005) showed the existence of mimicking behavior in French "departments" regarding local taxes, in particular for business tax, property tax on undeveloped land and property tax on developed land. Jayet et al. (2002) confirmed this result in tax mimicking for business tax in the Lille metropolitan area. The second generation of studies is based on the idea that evidence of sources of spatial dependence is hard to identify. To overcome this problem, recent studies (Agrawal (2013), Reback (2007), Eugster et al. (2013), and Lyytikäinen (2012)) have used regression (border) discontinuity designs and natural experiments to identify sources of spatial interactions by adopting novel spatial econometric techniques. For instance, Eugster et al. (2013) used a regression discontinuity approach to study tax competition in Swiss municipalities around the French/German language border. In a related paper, Agrawal (2013) investigated the spatial pattern of local sales tax rates in the U.S. at state borders where state sales tax rates change discontinuously.

Although this paper belongs to the first wave of empirical literature on spatial interaction, as our empirical strategy is based on a panel SAR model, it nevertheless makes significant contributions. It tests the existence of spatial interactions via a local indirect tax, namely the road tax sticker which to the best of our knowledge, has never been investigated for France. Furthermore, this paper seeks to quantify the link between local direct taxation (the 4 old taxes such as business tax, residence tax, property tax on undeveloped land and property tax on developed land) taking into account the potential spatial dependence between the 4 direct taxes and indirect local taxation, in particular the road sticker.

Results are the following. First, using a panel spatial econometric approach, I find evidence of spatial dependence, suggesting the existence of mimicking behavior in French departments when determining the rates of the road tax sticker. Second, the estimation results show that the business tax rate (resp. the property tax on developed land) and the road tax sticker are substitutes whereas the residence tax rate (resp. the property tax on undeveloped land) and the road tax sticker are complements. Third, estimation results on mobility of the road tax base must not be rejected. Finally, I find that departments with larger, younger and older populations set higher amounts for the road tax sticker.

The remainder of this paper is structured as follows. Section 2 presents both the French institutional context and the data used in the analysis. Section 3 specifies the empirical model and the construction of the weight matrix, and discusses the issues involved in the estimation. Section 4 provides the estimation results and analysis. Finally, the conclusion is presented in section 5.

1.2 Institutional context and data

Over the period 1984-2000, France had three overlapping tiers of jurisdictions: a bottom-most tier with more than 36,000 municipalities that could cooperate through inter-municipal groups, a middle-tier made up of 96 metropolitan "departments" and, just below the central jurisdiction, 22 metropolitan regions[5]. In this study, we focus on the middle-tier. Apart from a few exceptions, the borders of the departments in place today date back to 1790 and were chosen in such a way that it was possible to ride on horseback to the capital of a department in a single day.

The departments have been a key tier since the first phase of decentralization (1982-1986). The departments are administered by elected councils and wield executive powers including the management of most social and welfare allowances, departmental roads, and secondary schools. Indeed, the share of departmental expenditures in sub-national government expenditures was 31.28%

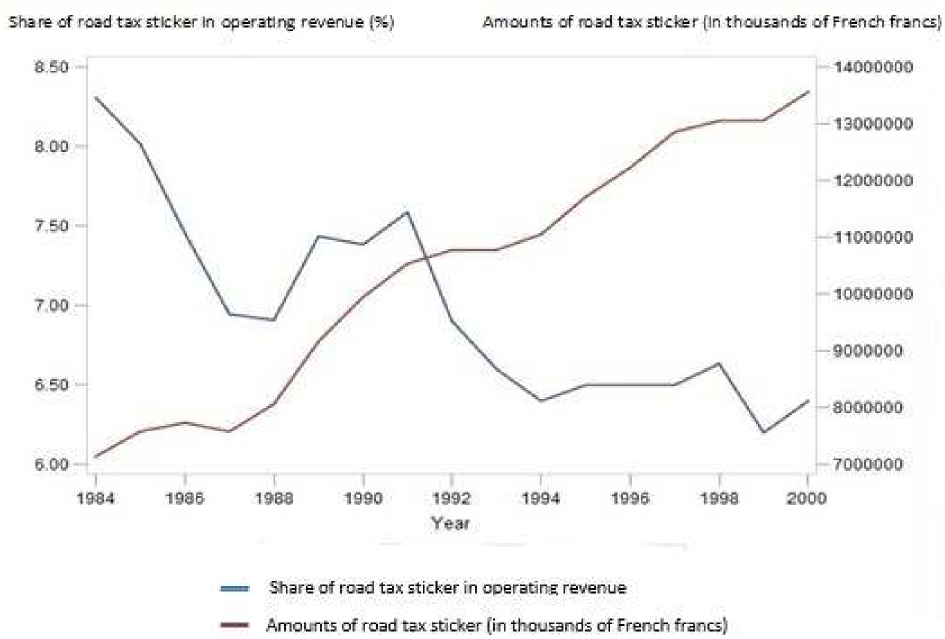
[4]Further developed, Edmark and Ågren (2008) tested for strategic interaction in Swedish municipal income taxes. Their results indicated the presence of positive spatial dependence in Swedish municipalities. Allers and Elhorst (2005) investigated the assumption that tax mimicking can be attributed to yardstick competition in Dutch municipalities and found strong evidence to support their premise.

[5]The law of January 16, 2015 on reducing the number of regions cut the number of metropolitan regions from 22 to 13, from January 1, 2016.

in 1984 and 29.77% in 2000. In order to offset the funding required for these new competences, additional fiscal resources were transferred to the department, including real estate transfer duties, the road tax sticker and new central grants, in addition to the four main direct taxes (residence tax, business tax, property tax on undeveloped land and property tax on developed land).

The road tax sticker was initially implemented in 1956 as an annual tax levied by central government on both private and company cars, that varied according to the vehicle's age and fiscal horsepower. The road tax sticker, created to finance the minimum income scheme for citizens aged 65 years old and older, was sold by tobacconists. In 1984, when the responsibility for levying this tax was transferred to the department, the amount paid for the road tax sticker for a given vehicle was no longer uniform across the country. Each department was free to choose the amount to be paid for the road tax sticker for the various categories of vehicles (based on vehicle age and fiscal horsepower).This road tax sticker was abolished in 2000 for private vehicles and then in 2006 for company cars, within the framework of a government plan to reduce the tax burden. When it was transferred in 1984, the road tax sticker on private cars represented 52.01% of indirect local taxation and 8.3% of total departmental revenues. In 2000, the contribution of this road tax was still relatively high, with 29.77% of indirect local taxation and 6.4%[6] of total departmental revenues. Figure 1.1 displays the evolution of revenues from the road tax sticker and its share in total operating revenues for all types of vehicles (company and private cars) over the period 1984-2000.

Figure 1.1: Evolution of share of revenues of road tax stickers in total operating revenues



[6]Calculated on the basis of official reports namely *"les budgets primitifs des départements en 2000"*.

This figure shows the evolution both in the share of revenues from the road tax sticker in total operating revenue and in the amounts of this road tax over the period 1984 to 2000. On average, the road tax sticker contributed 7% of total operating revenues. Before the abrogation of the road tax sticker in 2000 for private cars, the road tax sticker provided more than Frf13 billion to the departments in terms of revenue, making it an important source of revenues for them. The amount of road tax was based on the age (4 classes) and the fiscal horsepower of the vehicle (10 categories)[7].

1.3 Data

To test evidence of spatial interaction, I built an original panel dataset grouping 96 French metropolitan departments from 1984 to 2000. The period thus extends from the transfer of this new fiscal revenue to the department to the abolition of road tax stickers for private cars. I collected data on the road tax sticker from the Public Finance Archives Center ("Centre des Archives, de l'Economie et des Finances) via official tax returns over the 1984-2000 period. In addition to tax sticker rates, the analysis employs variables that capture time-varying locational characteristics. Firstly, I collected the associated tax bases given for each category of road tax sticker. However, it should be noted that the data on the tax base of the sticker are provided by age category, while the nomenclature of the amount of the road tax sticker is much finer. Indeed, according to table 1.5 (cf. appendix A), the road tax is distributed into 21 categories, consisting of (i) 10 categories for vehicles less than 5 years old, (ii) 10 other categories for vehicles 5-20 years old and (iii) one category for those over 20 years old. In this regard, road tax stickers are pooled in order to run the regressions using all categories as one dependent variable. In this case, I have 34,272 observations constituted by 21 categories[8] of road tax for the 96 French metropolitan "départements" from 1984 to 2000. In addition, information on the transport sector, such as vehicle registration[9], is included. More specifically, I also consider the share of new and second-hand vehicles registration as an explanatory variables.

Secondly, to quantify the relationship between direct and indirect taxation, I collected data on direct taxation levied by the department, namely residence tax, business tax, property tax on developed land and property tax on undeveloped land, from the yearly publication "Les finances des "départements" published by the French Ministry of the Interior. Local taxes may be either strategic complements (positive sign) or strategic substitutes (negative sign) of, the road tax sticker. As a financial variable, I also included data related to income tax to capture its effect on demand for

[7] See appendix for more details.

[8] We also carried out an analysis which specifies three aggregated categories of road tax stickers, namely i) private cars less than 5 years old of 1 to 7 CV, ii) private cars between 5 to 20 years old of 1 to 7 CV and iii) private cars older than 20 years of all powers - in sense that vehicles of less than 8 CV represented 90% of the French fleet of private cars in 2000. Estimation results found strong evidence of spatial dependence of each category of road tax sticker.

[9] French registration plate is one of the elements of the system designed for the identification of vehicles in the French car fleet. Indeed, the registration plate system is geographical and the vehicles are registered with the prefectures of their respective departments. Hence this system uses codes that indicate the department on it, with exceptions (Corsica and overseas departments). However, since 2009 the driver has complete freedom to choose his registration department, regardless of his place of residence.

departmental public services, hence on the road tax sticker. The expected sign is positive if public services are normal goods (Leprince et al. (2007), Dubois et al. (2007)).

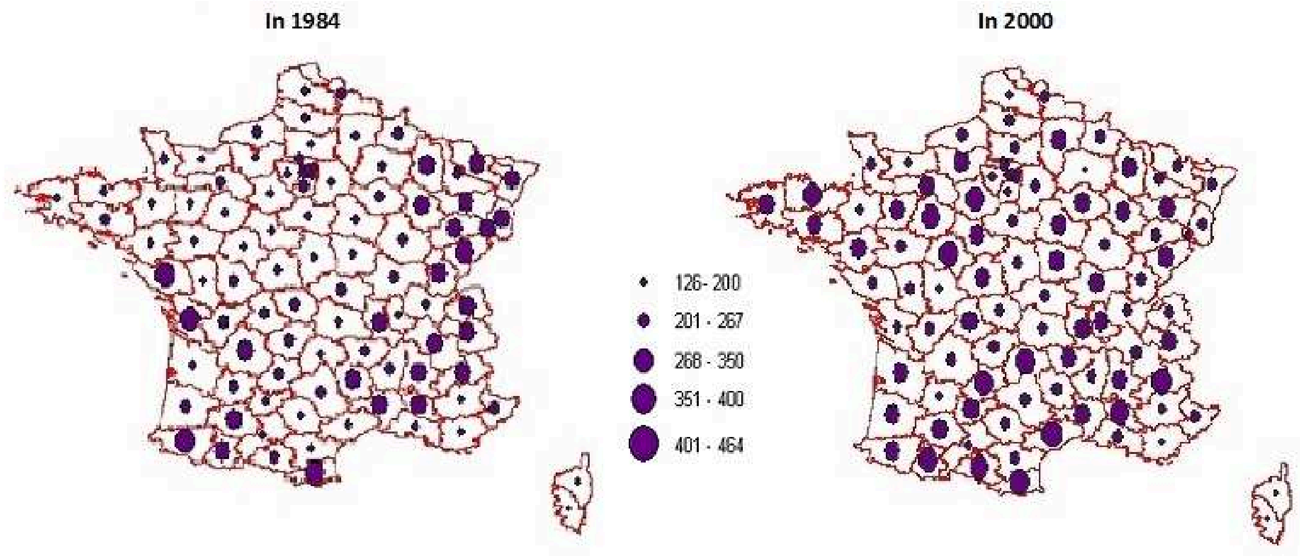
Thirdly, I also collected standard socioeconomic variables, such as total population, unemployment rate, share of the young (younger than 15) and the elderly (over 60) in the population in each department from the French National Institute for Statistics and Economic Studies (INSEE). These socioeconomic variables are introduced to control for different spending needs or preferences for public goods in the departments. Note that the expected signs for population are often considered positive for various reasons. For instance, Leprince et al. (2007), Heyndels and Vuchelen (1998) and Cassette and Paty (2008) consider that the higher the expenditure needs, the heavier the fiscal burden and the higher the tax rates. According to Bartolini and Santolini (2012), a positive relation between population and local tax signifies the presence of congestion effects. The variables of unemployment rate and the population share of the young (under 15) and the elderly (over 60), can be interpreted as expenditure needs indicators and may have a positive sign (Heyndels and Vuchelen (1998), Dubois et al. (2007), Leprince et al. (2005)). Indeed, they represent categories of people who have specific public spending needs and benefit from department programs.

Finally, I also control for political effects, such as the scrapping premium and party color. Through party color, I allow for systematic differences in tax setting behavior between left-wing and right-wing incumbents (Revelli (2001)). This party color variable is a dummy variable equal to one if the departmental council is controlled by the right-wing, and zero otherwise. A negative sign of this variable suggests that a departmental council controlled by the right-wing will tend to set a lower rate for the road tax sticker than the left-wing (or vice versa). In addition, I take into account the electoral calendar to test its impact on the road tax sticker. As for the scrapping premium, the aim is to measure the impact on the road tax sticker of a policy in which the French government subsidized the replacement of old cars with new ones. However, to the best of my knowledge, there are no papers providing an intuitive view of the impact of the scrapping premium on local tax. Table **??** presents a summary of statistics for all the dependent and explanatory variables. It should be noted that both the road tax stickers and the income tax variable are expressed in constant French francs.

Table 1.1: Descriptive statistics

	Definition	Source	Mean	St. Dev.	Min	Max
Dependent variables						
Road tax	Road tax sticker for all categories and age for vehicles in current French francs	CAEF	2,930	3,310.11	30	16,240.76
Road tax base	Number of stickers delivered for all age for vehicles	MDD	97,366.95	107,273.6	92	761,147
Explanatory variables						
Undeveloped__rate	Undeveloped property tax rate	DGCL	24.51	14.67	0	97.37
Developed__rate	Developed property tax rate	DGCL	8.43	2.94	0	19.53
Residence__rate	Residence tax rate	DGCL	6.69	2.00	0	12.36
Business__rate	Business tax rate	DGCL	5.70	1.39	0	11.41
Income__tax	Amount of net income tax in constant french francs	INSEE	2,996,438,214	4,410,071,883	186,157,594	43,112,693,331
Population	departmental population	INSEE	593,322.20	452,563.40	72,390	2,555,471
Percentage__Young	% of young people (under 15 years old)	INSEE	0.20	0.03	0.14	0.31
Percentage__Older	% of older people (over 60 years old)	INSEE	0.21	0.04	0.11	0.34
Unemployment	Unemployment rate (%)	INSEE	0.09	0.02	0.04	0.16
Share second-hand vehicles registration	Share of registrations of second hand vehicles	MDD	0.70	0.06	0.20	0.93
Share new vehicles registration	Share of registrations of new vehicles	MDD	0.30	0.06	0.07	0.80
Right	Dummy variable that equals one if the local council is controlled by the right-wing	INSEE	0.73	0.44	0	1
Schedule	Electoral schedule	INSEE	0.29	0.46	0	1
Scrapping__1994	Scrapping premium in 1994	INSEE	0.06	0.24	0	1
Scrapping__1995	Scrapping premium in 1995	INSEE	0.06	0.24	0	1
Scrapping__1996	Scrapping premium in 1996	INSEE	0.06	0.24	0	1

Figure 1.2: Road tax sticker for vehicles less than 5 years old in 1984 and 2000



As a preliminary spatial analysis, figure 1.2 provides information on the spatial distribution of the road tax sticker for vehicles less than 5 years old over the study period (1984-2000). The spatial pattern for the road tax sticker is illustrated in the maps in figure 1.2 in which the largest point corresponds to the highest road tax sticker rates for vehicles less than 5 years old. These maps seem to show that the spatial distribution of the road tax sticker is not random, in particular the map of road tax stickers for 1984. This map shows a concentration of the highest road tax sticker rates in the eastern French departments (neighbors are similar to each other) and lower values in the rest of France. We investigate in the next section whether these spatial patterns are representative of spatial interactions.

1.4 Methodology

1.4.1 Empirical design

In line with the first generation of empirical studies on strategic interactions among local governments, the spatial lag model is theoretically appropriate in the situation where the local tax of one jurisdiction interacts with the tax of its neighboring jurisdictions (Brueckner and Saavedra (2001), Brueckner (2003), Revelli (2001), Revelli (2003), Ollé (2003)). Specifically, this model with a lagged dependent variable is appropriate when the tax rate of one jurisdiction depends on the tax rates of its neighbors and a range of other local characteristics (Allers and Elhorst (2005)).

To test the presence of strategic tax interactions, I use a static spatial lag panel data model in which the value of the dependent variable for one department i depends on the value of the dependent variable observed in neighboring units and on a set of observed local characteristics. I also include the spatial lags of certain independent variables in order to specify an unconstrained spatial Durbin model, as I suspect the presence of spillover effects for some but not all explanatory variables. It should be noted that since there are 21 categories of road tax, the road sticker taxes are pooled into one model so that each observations corresponds to a triplet department-category-year. Formally, let the index $i = 1, ..., N$ denote department i, $p = 1, ..., P$ denote the road tax p and $t = 1, ..., T$ denote time period t. Then, the model for each department and road tax at time t includes a spatially lagged dependent variable in addition to spatial lags of independent variables, and is expressed by the following equation:

$$\tau_{ipt} = \rho \sum_{j=1}^{N} w_{ij}\tau_{jpt} + x_{it}\beta + \sum_{j=1}^{N} w_{ij}z_{it}\theta + \mu_i + \varepsilon_{ipt} \tag{1.1}$$

where τ_{ipt} denotes the road tax sticker for category p in location i at time t. x_{it} is a $1 \times k$ vector of explanatory (exogenous) variables (we use the same set of variables for all categories of road tax stickers), while z_{it} is a $1 \times k_1$ matrix consisting of a subset of X_{it} with $k_1 < k$; β and θ are respectively $k \times 1$ and $k_1 \times 1$ vector of unknown parameters to be estimated. Parameter ρ is the spatial autoregressive parameter indicating the magnitude of the interaction among departments through the road tax sticker. If it is significant, spatial interactions exist among departments. In addition, if it is positive, it means that the department adopts a mimicking behavior. On the other hand, if this coefficient is negative, the department adopts a strategic behavior of differentiation. μ_i is an individual effect capturing all time-invariant locational characteristics at the level of the department. The weight w_{ij} is the element ij of the matrix W of dimension $N \times N$. W contains known elements with zero diagonal elements and is row-normalized. ε_{ipt} refers to the error term which is assumed to be independent and identically distributed: ε_{ipt} is i.i.d $\mathrm{N}(0, \sigma_\varepsilon^2)$.

Equation 1 can be written in stacked form as follows:

$$\tau_{pt} = \rho W\tau_{pt} + X_t\beta + WZ_t\theta + \mu_j + \varepsilon_{jt} \tag{1.2}$$

where τ_{pt} denotes the $N \times 1$ vector of observations of the dependent variable (the road tax sticker) for a category p in period t; X_t denotes the $N \times k$ matrix of observations of exogenous regressors in period t, invariant for all categories p; Z_t is the $N \times k_1$ matrix consisting of a subset of X_t; W is $N \times N$ non-stochastic weight matrix. Finally, μ_j is a $N \times 1$ vector of individual specific effects for τ_{pt} (not spatially autocorrelated).

Due to the presence of simultaneity bias between the road tax sticker and its tax base, I omit the right hand side road tax base variable from the first regression. Instead, in line with Buettner (2003), I use the road tax base as a left hand side variable in order to test how mobile the tax base of the road tax sticker is across departments in response to the tax rate of a given department and that of a neighboring department. Hence, the road tax base model is written as follows:

$$b_{kt} = \alpha_1 \tau_{kt} + \alpha_2 W \tau_{kt} + \alpha_3 X_t + \nu_{kt} \tag{1.3}$$

where b_{kt} denotes the road tax base of age category k in period t. τ_{kt} and $W\tau_{kt}$ are respectively the road tax of a given department and its spatial lag[10] in period t. X_t represent the matrix of explanatory variables described in the equation 3.1 . $\boldsymbol{\alpha_1}$, $\boldsymbol{\alpha_2}$ and $\boldsymbol{\alpha_3}$ are vectors of unknown parameters to be estimated. ν_{kt} represents the error term which is assumed to follow a first-order spatial autoregressive process:

$$\nu_{kt} = \lambda W \nu_{kt} + \eta_{kt} \tag{1.4}$$

where λ is a parameter describing the intensity of the spatial autocorrelation between the regression residuals. η_{kt} is i.i.d.$(0, \sigma_v^2)$.

1.4.2 Spatial dependence and econometric issues

In order to test for spatial interactions, it is necessary to create spatial neighbors. Neighbor relationships are defined by the elements of the matrix W. While a variety of weighting schemes could be applied, I construct a commonly used weight matrix, namely the contiguity matrix. Two departments are contiguous when they share a common border ($w_{ij} = 1$, otherwise $w_{ij} = 0$). To check robustness, I also consider an alternative weight matrix, i.e. the inverse distance which is a geographical definition of neighborhood based on the inverse geographical distance between departmental prefectures, since it is the latter which have the administrative obligation to issue the road tax sticker. This scheme imposes smooth distance decay, with weights $w_{i,j}$ given by $1/d_{i,j}$ where $d_{i,j}$ is the distance between departmental prefectures if this distance is shorter than a cut-off distance. The cut-off distance is set to 621 km, which corresponds to the first quartile of the distance distribution. However, as the row-normalizing norm may be not neutral, I consider an alternative normalization of weight matrices. Hence, I recalculate weight matrices based on

[10] As explained in previous section, the road tax base is provided into 3 categories (k = 1 to 3) depending on vehicles age, namely the number of stickers delivered for vehicles less than 5 years old, those for vehicles between 5 - 20 years old and the number of stickers for vehicles over 20 years old and less than 25 years old.

Kelejian and Prucha (2010). Therefore, all the estimations are made by taking into account these alternative normalization weight matrices.

Furthermore, to estimate a spatial panel model with individual fixed effects, I use the Maximum likelihood (ML) approach[11], where the likelihood function corresponds to the normal distribution (Lee and Yu (2010)). Besides, I discuss certain issues pertaining to the specification when estimating the static panel spatial lag model. In particuar, the interpretation of the parameters becomes complex (but also more complicated) with the introduction of spatial lag parameters. In model containing spatial lags, LeSage and Pace (2009) and Kelejian et al. (2006) argued that the spatial dependence in the lag model needs special interpretation because a change in the explanatory variable for an observation can affect the dependent variable in all other observations. Therefore, the parameters of the spatial lag model must be interpreted correctly in terms of impact measures (direct, indirect and total). The detailed derivations of the direct effects, indirect effects (spatial spillover), and total effects of each variable on the dependent variable can be found in Elhorst (2014) in a spatial panel data setting.

1.5 Estimation results

I present an estimation with contiguity as the weight matrix using 4 specifications. The first estimates the road tax sticker on the set of direct taxation variables, the second estimates the dependent variable on these latter variables and their spatial lag variables. In the third regression, I add a set of socio-economic variables and in the last one I exclude regression variables related to direct taxation. Table 1.3 displays the results of these estimations using SAR (spatial autoregressive) models by adding individual fixed effects[12].

Result 1: *department road tax rates exhibit positive spatial correlation with neighboring "departments".*

The SAR model estimation results (table 1.3) tend to confirm evidence of department spatial interactions for the French road tax sticker. Indeed, the spatial auto-regressive parameter (ρ) is positive and strongly significant regardless of the underlying model (column 1-4) with coefficients varying from 0.3087 to 0.3103. The resulting significance of this parameter indicates the strength of the interactions existing between departments via the road tax sticker.

It is noteworthy that this finding is in line with those of many first generation studies in the empirical literature on spatial interaction. In French cases, Leprince et al. (2005) assumed mimicking behavior among French departments for business tax, as well as taxes on undeveloped and

[11]Noted that space parameter ρ is contrained when using maximum likelihood approach. However, Anselin and Florax (1995) point out that this parameter can take on feasible values in the range:

$1/\lambda_{min} < \rho < 1/\lambda_{max}$, where λ_{min} represents the minimum eigenvalue of the standardized spatial contiguity matrix W and λ_{max} denotes the largest eigenvalue of this matrix.

[12]Table 1.7 in the appendix displays estimation results of SAR regression including time fixed effects. Results show that spatial dependence remains consistent.

developed land. Jayet et al. (2002) showed the existence at a lower tier of tax interactions among municipalities for French local business tax. At the regional tier, Feld et al. (2002) confirmed this assumption of spatial interactions between local taxes. Similar studies have been performed internationally and provided evidence of tax interactions among locations. Edmark and Ågren (2008) tested the hypothesis of strategic interactions of income tax in Swedish municipalities. Their results indicated the presence of positive spatial dependence. Allers and Elhorst (2005) found strong evidence of tax mimicking among Dutch municipalities. The distinctiveness of this study on empirical works relating to spatial interaction is that it was devoted to a specific indirect local tax on vehicles, namely the road tax sticker.

Table 1.2: Spatial dependence and direct effects with contiguity weight matrix

	Dependent variable:Road tax sticker			
	Contiguity matrix			
	(1)	(2)	(3)	(4)
Neighboring road tax	0.3090*** (0.0160)	0.3103*** (0.0160)	0.3087*** (0.0160)	0.3091*** (0.0160)
Business_rate	0.0082*	0,0069*	0,006*	
Residence_rate	−0.0320***	−0,0384*	−0,0290	
Undeveloped_rate	−0.0012*	−0,0011*	−0,0007	
Developed_rate	0.0190***	0.0202*	0.0170	
log(Income_tax)			−0.0809*	−0.0675*
log(Population)			0.1595***	0.1365***
Percentage_Young			1.689**	2.3878***
Percentage_Older			1.5684***	2.1303***
Unemployment			−1.4199***	−1.7150***
Right			−0.014	−0.0250
Scrapping_1994			0.0119	0.0216
Scrapping_1995			0.0170	0.0202
Scrapping_1996			−0.1035	−0.146**
Schedule			0.0185	0.0189

Note : *p<0.1; **p<0.05; ***p<0.01

Result 2: *the business tax rate (resp. the property tax rate on developed land) and the road tax sticker are complements whereas the residence tax rate (resp. the property tax rate on undeveloped land) appears as substitutes to the road tax instrument.*

Regarding the explanatory variables, it should be noted that the interpretation of the parameters requires the calculation of impact measures as stated in section above. Therefore, I computed the direct, indirect and total effects of each variable using also contiguity as a spatial weight matrix. It should be noted that inference is conducted using bayesian approach such as Markov Chain Monte Carlo (MCMC). With regard to these other covariates, there are additional findings worth mentioning. Firstly, Table 1.2 shows significance for the business tax rate regardless the specification (columns 1-3) whereas other three of the four direct taxation variables appear significant in the two first models (i.e when estimating without the set of socio-economic variables). More specifically, estimation results indicate that a high road tax is associated with a high business tax and/or a high property tax on developed land. However, a low residence tax rate and/or a low property tax on undeveloped land are related with a high road tax sticker. Hence, the business tax rate and/or the property tax rate on developed land are complements to the road tax sticker whereas the residence tax rate and the property tax rate on undeveloped land appear as substitutes to the road tax instrument. This finding brings a new contribution to the relationship between direct and indirect local taxation. This behavior of exhibited by elected officials at the department level could be explained by the simultaneous voting of different local tax rates. For instance, according to the relationship between the residence tax rate and the road tax sticker, a given department adopts a strategic behavior by decreasing the sticker tax rate while raising the residence tax rate, in order to avoid being considered a high "spending" department. Also, the observation of synergy between the business tax rate and the road tax sticker implies that the department appears to have consistent tax policies in which the level of the road tax sticker is positively affected by the level of the business. This behavior may be motivated by the wish to diversify tax revenues from different taxes or by the department's "spending behavior". Similar analysis is consisistent for the relationship between the property tax on developed land and the road tax sticker. Secondly, income tax appears to be negative and significant regardless of the specification (column 3-4 in table 1.2), suggesting that it is a substitute with the road tax sticker. Finally, with respect to the other control variables, the results indicate significant and positive impacts of population size, while the unemployment rate of the latter seems to be negative and significant. The positive relationship between population and road tax might result from Oates "Zoo-effect" (Oates (1988)), reflecting that larger departments provide a wider range of services, therefore they need a higher level of tax in order to ensure their services. Table 3 also shows that the age structure of the local population affects the rate of the road tax sticker, particularly when an older or younger population is associated with higher road tax. Furthermore, according to the political variables, both the right party color and the electoral calendar appear insignificant. As for the scrapping premium, its impact is also marginal.

Result 3: *the road tax base seemed to be mobile.*

As mentioned in emprical strategy, I consider road tax base as a left hand side variable in order to test how mobile is the road tax instrument (Buettner, (2003)). Table 1.3 displays the estimation results indicating that the road tax rate has a negative and significant impact on the tax base of sticker. This finding is expected implying that the expand tax base means lower tax rate (columns 1-3). As a neighboring effects, I also find that the neighboring tax rate has positive and significant impacts on the road tax base (colums 2-3) - suggesting that the hypothesis of mobility of the road tax base cannot be rejected. Indeed, mobility means that the tax base expands with respect to the increase of neighboring tax rate. However, this result should be considered with caution. Indeed, as explained earlier, the average road tax rate is used when testing the mobility of its tax base[13]. Therefore estimation results based on average road tax may be biased. Furthermore, I investigated an alternative and robust way of accessing mobility using registration data. Table 1.3 displays results on registrations which shows that the share of registration of second-hand vehicles has a positive and significant impact on the tax base of the sticker (columns 4-6) while the share of registrations of new vehicles impacts negatively the tax base of the sticker (columns 7-9). This result reveals that the higher is the share of registrations of second-hand vehicles (resp.

the lower is the share of registrations of new vehicles), the higher is the road tax base. Regarding the neighborhood effects, table 1.4 also shows a negative relationship between both the share of registrations of new and second-hand vehicles and the tax base of the sticker suggesting that the hypothesis of mobility of the tax base of the sticker must not be rejected. Indeed, the higher is the share of registrations of new or second-hand vehicles in neighbors of a given department, the lower is the road tax base in that department. Hence, based on registrations data, the road tax base seems to be mobile. It is noteworthy that the value of the spatial error autocorrelation (λ) is positive and significant, regardless of the regression, (table 4). This finding could be explained by the omission of certain spatial variables that might be significant.

[13]The panel dataset used to access mobility of the road tax base contains 4,896 observations, i.e 96 departsments from 3 category of tax base over the period 1984-2000 (96*3*17 observations.)

Table 1.3: Estimation of the base of road tax with contiguity weight matrix

	Dependent variable:								
	Table road tax base contiguity								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
log(Road tax)	−0.0962**		−0.0878**						
	(0.0419)		(0.0419)						
log(Neighboring road tax)		0.0251***	0.0244***						
		(0.0063)	(0.0063)						
Share second-hand vehicles registration				0.2200***		0.2417***			
				(0.0535)		(0.0541)			
Neighboring Share second-hand vehicles registration					−0.1600*	−0.2215**			
					(0.0864)	(0.0872)			
Share new vehicles registration							−0.2492***		−0.2623***
							(0.0311)		(0.0310)
Neighboring Share new vehicles registration								−0.1472***	−0.1622***
								(0.0258)	(0.0257)
log(Income_tax)	0.0164	0.0315	0.0282	0.0441	0.0256	0.0548*	0.0654**	0.0345	0.0850***
	(0.0283)	(0.0284)	(0.0284)	(0.0289)	(0.0285)	(0.0292)	(0.0286)	(0.0283)	(0.0287)
log(Population)	0.9264***	0.8998***	0.9090***	0.8842***	0.9081***	0.8688***	0.8551***	0.8953***	0.8270***
	(0.0357)	(0.0357)	(0.0360)	(0.0364)	(0.0358)	(0.0369)	(0.0361)	(0.0356)	(0.0362)
Percentage_Young	−0.8424	−1.0884**	−0.8906*	−1.6224***	−1.0796**	−1.7093***	−2.1737***	−1.0759**	−2.2114***
	(0.5335)	(0.5234)	(0.5321)	(0.5382)	(0.5243)	(0.5378)	(0.5359)	(0.5224)	(0.5334)
Percentage_Older	4.0830***	3.8907***	4.0437***	3.5213***	3.9225***	3.4909***	3.0801***	3.8464***	2.9683***
	(0.3312)	(0.3226)	(0.3308)	(0.3358)	(0.3230)	(0.3356)	(0.3367)	(0.3222)	(0.3357)
Unemployment	−0.1549	0.1065	−0.0183	0.1759	0.0347	0.2737	0.3432	0.1332	0.5236*
	(0.3065)	(0.3017)	(0.3075)	(0.3036)	(0.3021)	(0.3053)	(0.3016)	(0.3007)	(0.3015)
Right	0.0143	0.0127	0.0123	0.0197	0.0155	0.0213	0.0246*	0.0093	0.0185
	(0.0130)	(0.0130)	(0.0130)	(0.0131)	(0.0130)	(0.0130)	(0.0130)	(0.0130)	(0.0130)
Scrapping_1994	0.0323	0.0297	0.0310	0.0289	0.0301	0.0276	0.0271	0.0298	0.0260
	(0.0219)	(0.0217)	(0.0217)	(0.0217)	(0.0219)	(0.0216)	(0.0214)	(0.0216)	(0.0213)
Scrapping_1995	0.0723***	0.0699***	0.0713***	0.0701***	0.0700***	0.0691***	0.0711***	0.0710***	0.0718***
	(0.0217)	(0.0215)	(0.0214)	(0.0215)	(0.0216)	(0.0213)	(0.0212)	(0.0214)	(0.0210)
Scrapping_1996	0.1293***	0.1443***	0.1322***	0.1923***	0.1404***	0.1945***	0.2453***	0.1505***	0.2572***
	(0.0422)	(0.0416)	(0.0420)	(0.0432)	(0.0418)	(0.0431)	(0.0431)	(0.0416)	(0.0429)
Schedule	−0.0121	−0.0124	−0.0123	−0.0173	−0.0103	−0.0152	−0.0270**	−0.0171	−0.0332***
	(0.0114)	(0.0113)	(0.0113)	(0.0114)	(0.0114)	(0.0113)	(0.0113)	(0.0113)	(0.0113)
lambda	0.2999***	0.2872***	0.2847***	0.2868***	0.2969***	0.2753***	0.2732***	0.2842***	0.2640***
	(0.0424)	(0.0425)	(0.0425)	(0.0425)	(0.0424)	(0.0427)	(0.0427)	(0.0425)	(0.0428)

Note: *p<0.1; **p<0.05; ***p<0.01

1.6 Robustness checks

To check for the robustness of these results, all the models are estimated by changing the weight matrix. Rather than using a contiguity matrix, we use inverse distance as the weight matrix. The results obtained for the SAR model are shown in table 1.4. With respect to spatial dependence using an inverse distance matrix, the results point to a spatial autocorrelation of the road tax sticker. The estimate of the spatial lag coefficient ρ is large and statistically significant in all specifications (columns 1-4). Indeed, in the SAR specification (table 1.4) relating to road tax stickers for private cars, it was observed that the spatial lag is strong and positive with a coefficient varying from to 0.4024 to 0.4053, which means that French departments mimic each other when setting the road tax for this category of private car users. Therefore, using inverse distance, the estimation results confirm the finding that departments take into account the amount of the road tax sticker set by their neighbors when deciding the amount of this road tax. Hence SAR specifications of the first order spatial autoregressive coefficient on the lagged dependent variable (ρ) - using both contiguity and inverse distance as weight matrices - yield the same results. The fact that the two specification methods yield virtually the same outcome is reassuring, and confirms the existence of tax interactions among French departments via the road tax sticker. In other words, departments seems to increase the rate of their road tax sticker on private cars in response to a rise in the rate of road tax stickers in their neighboring departments.

Table 1.4: SAR regression with inverse distance weight matrix

	Dependent variable:Road tax sticker			
	inverse distance weight matrix			
	(1)	(2)	(3)	(4)
Neighboring road tax	0.4035***	0.4041***	0.4053***	0.4024***
	(0.0189)	(0.0189)	(0.0189)	(0.0189)
Business_rate	0.0104**	0.0093*	0.0091*	
Residence_rate	−0.0384***	−0.0392*	−0.0354*	
Undeveloped_rate	−0.0014**	−0.001**	−0.0007**	
Developed_rate	0.0199***	0.021**	0.0176**	
log(Income_tax)			−0.0979**	−0.0790**
log(Population)			0.1862***	0.1572***
Percentage_Young			1.5405*	2.2525***
Percentage_Older			1.5533***	2.1743***
Unemployment			−1.5101***	−1.8876***
Right			−0.0010	−0.0145
Scrapping_1994			0.0119	0.0220
Scrapping_1995			0.0175	0.0197
Scrapping_1996			−0.0933	−0.1378**
Schedule			0.0185	0.0197

Note 1: *p<0.1; **p<0.05; ***p<0.01
Note 2: Regarding covariates, only direct effects are reported in this study.

Regarding the set of independent variables, using the inverse distance weights matrix, our main results remain valid. For instance, table 1.4 shows a positive and significant sign for both the parameters associated with the business tax rate and the property tax rate on developed land in all specifications (columns 1-3), confirming that these two local direct tax instruments and the road tax sticker are complements. Moreover findings show that the residence tax rate and/or the property tax rate on developed land remain as substitutes to the road tax sticker. In brief, the estimation results tend to confirm the relationship between direct taxation and indirect taxation. In addition, with respect to the other covariates, table 1.4 also shows that the departmental population, and its components have positive (or negative) and significant values, implying that departments with larger, younger and older populations (for example, with larger unemployment rates) tend to set higher (or lower) rates for road tax stickers. Thus the estimation results using inverse distance confirm the robustness of the previous results in the sense that they are close in magnitude to those obtained using the contiguity weights matrix.

1.7 Conclusion

This paper presented an empirical investigation of road tax interaction among French departments using panel data from 96 departments over the period 1984-2000. By applying a spatial econometric approach to the French departments, I first found strong evidence in favor of spatial autocorrelation of the French road tax sticker. This finding is in accordance with the first generation of empirical studies in the literature on spatial interactions, suggesting that French metropolitan departments react to the tax policies of their neighbors by adjusting their own road tax sticker rates towards those chosen in nearby departments, *ceteris paribus*. Secondly, by specifying a spatial panel with fixed effects, I also investigated the relationship between direct and indirect local taxation. In particular, I found an economically and statistically significant effect of direct taxes on the road tax sticker. More specifically the business tax rate and/or the property tax rate on developed land are complements to the road tax sticker whereas the residence tax rate and/or the property tax rate on undeveloped land are substitutes to the road tax instrument over the period of study. In addition, estimation results tend to confirm the mobility of road tax base. Finally, I found that the proxy variables for local cost factors (population and unemployment) impact road tax setting. In other words, in departments where there is a larger, older and younger population, and with a smaller unemployment rate, the amounts of the road tax sticker tend to be higher.

At least three main factors have a significant influence on vehicle taxation systems and more specifically on road tax systems. The first is related to the existence of different taxation levels. Indeed, as the road tax was levied by local governments (departments), the amount of this tax would have an impact on expected revenues. Therefore, low taxation could be considered as a short-term opportunity to increase tax revenue through increased sales of stickers (by raising the road tax base). Linked to the previous point, a second factor possibly impacting the vehicle taxation system is based on the behaviour of the stakeholders (individuals and local authorities). With respect to these two first factors, our study found evidence of spatial interaction among French departments related to this indirect local vehicle taxation. To illustrate this behaviour, and more specifically that of a local authority, Marne department was known for setting very low rates for road tax stickers from 1996 to 1999 during which it fixed a sticker price of less than half the average of the other departments. As a result, sticker revenues in this department doubled. However, from the citizen's viewpoint, beyond considerations regarding different levels of welfare, the level of household mobility becomes an important issue when assessing the impact of individual behaviour on the road tax system. Finally, the last point is related to environmental issues[14] which can modify vehicle taxation system. Although the French road tax sticker did not have an environmental goal, most EU countries now levy an annual circulation tax (i.e. tax sticker) on cars as an instrument for mitigating air pollution, with different rates applied to diesel and gasoline vehicles and/or to engine size[15].

In addition, this innovative database and methodological approach may be used for further research. First, standard spatial econometric methods have been severely criticized over the last ten years (Corrado and Fingleton (2012), McMillen (2010), Gibbons and Overman (2012). According to Corrado and Fingleton (2012), standard spatial econometrics is typically applied in a mechanical fashion and there is a lack of theoretical foundations for variables that characterize spatial econometric models. McMillen (2010) put forward similar arguments by claiming that the main problem - when adopting standard models used to address spatial autocorrelation - is that they are likely to fail in identifying the root cause of spatial autocorrelation. Thus he pointed out the weakness of conventional spatial econometric methods in terms of identification and causality. Regarding the same issue, Gibbons and Overman (2012) argued that reliable estimation of causal spatial interaction parameters requires quasi-experimental settings that lead to exogenous variations in the variable of interest. Hence, an important issue for future research will be to apply regression discontinuity design (RDD) or natural experiments to identify the source of spatial interactions. Secondly, the presence of endogenous variables on the right-hand side is a common occurrence in applied econometrics work. However, due to the lack of adequate instrument variables, we did not conducted an instrument variables method in order to deal with endogeneity bias. Finally, further research should be conducted to assess the impact of the road tax sticker on the car fleet.

[14]This work does not explicitly address this point since the French road tax sticker did not have an environmental objective. Furthermore, it is well known that the transport sector is one of the most significant sources of air pollution worldwide. Indeed, transport is responsible for more than half of NOx emissions, and contributes significantly (around 15 % or more) to the total emissions of the other pollutants. In particular, road transport makes a significant contribution to emissions of all the main air pollutants.

[15]In Austria, to incite owners to scrap their vehicles not equipped with catalytic converters or to equip them, the road tax sticker for non-equipped vehicles is 20% higher. The most interesting example is that of Denmark which, in July 1997, changed from a road sticker based on the weight of vehicles to one based on their unit consumption with the objective of reducing emissions. In the Netherlands, the road tax sticker is based on the type and weight of vehicles and the fuel used. Germany has a similar calculation system, since the road sticker is based on power and pollutant emissions.

1.8 Appendices

1.8.1 Appendix A1: Classification of the road tax sticker

Table 1.5 provides an overview on the characterisation of sticker taxation structure[16], highlighting the three broad age categories[17] in which the road tax instruments applied to vehicle owners in two French departements, namely Paris and Marne[18].

Table 1.5: Classification of road tax stickers in 1984 and 2000

Year	1984		2000	
Amount of road tax sticker for vehicles less than 5 years old				
Power (in horsepower)	Paris	Marne	Paris	Marne
1 - 4	234,34	248,63	260,27	142,86
5 - 7	500,11	468,68	493,15	272,02
8 - 9	1185,98	1114,53	1170,25	645,79
10 - 11	1397,45	1317,44	1379,65	796,48
12 - 14	2477,70	2343,38	2444,23	1412,92
15 - 16	2477,70	2343,38	2992,17	1727,98
17 - 18	3717,97	3515,07	3667,32	2119,37
19 - 20	12654,25	11862,64	5487,28	3170,25
21 - 22	12654,25	11862,64	8242,66	4763,21
23 and more	12654,25	11862,64	12375,73	7152,64
Amount of road tax of for vehicles between 5-20 years old				
1 - 4	131,46	124,31	130,14	71,43
5 - 7	250,06	234,34	246,58	136,01
8 - 9	592,99	557,27	585,13	322,90
10 - 11	698,73	658,72	689,82	398,24
12 - 14	1238,85	1171,69	1222,11	706,46
15 - 16	1238,85	1171,69	1496,09	863,99
17 - 18	1858,99	1757,53	1833,66	1059,69
19 - 20	6327,12	5931,32	2743,64	1585,13
21 - 22	6327,12	5931,32	4121,33	2381,60
23 and more	6327,12	5931,32	6187,87	3576,32
Amount of road tax sticker for vehicles over 20 years old and less than 25 years old				
All power	110,02	110,02	103,72	55,77

[16] All amounts of road tax are expressed in constants French francs.

[17] The fourth age category corresponds to the vehicles over 25 years old for which the road sticker was free but was still mandatory.

[18] The choice of department of Paris is based on the fact that Paris is the capital of France whereas the department of Marne is chosen for its particular characteristic of road taxation by imposing the lowest amounts of the road sticker during the 1990s.

1.8.2 Appendix A2: Estimation results using modified contiguity weight matrix

Table 1.6 compares estimation results using modified contiguity and those with standard contiguity. Since, the definition of neighbourhood by contiguity excludes the Corsican island in which there are two "départements" (Upper Corsica and Southern Corsica), I have attached the Corsican "départements" to their nearest neighbors which are the "départements" of Var and Alpes-Maritimes, in order to connect Corsica to the other French "départements". The finding (table 1.6) indicates that interactions between Corsica and other French "départements" are less important since spatial interaction parameter (*rho*) is smaller when using modified contiguity than standard contiguity.

Table 1.6: SAR regression with contiguity and modified contiguity weight matrices

	Dependent variable:							
	contiguity weight matrix				modified contiguity weight matrix			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Neighboring road tax	0.3090***	0.3103***	0.3087***	0.3091***	0.1328***	0.1335***	0.1326***	0.1327***
	(0.0160)	(0.0160)	(0.0160)	(0.0160)	(0.0078)	(0.0078)	(0.0078)	(0.0078)
Business_rate	0.0082*	0.0072	0.0065		0.0079*	0.0069	0.0062	
	(0.0044)	(0.0044)	(0.0049)		(0.0044)	(0.0044)	(0.0049)	
Residence_rate	−0.0320***	−0.0331***	−0.0293***		−0.0324***	−0.0334***	−0.0295***	
	(0.0069)	(0.0072)	(0.0077)		(0.0069)	(0.0072)	(0.0077)	
Undeveloped_rate	−0.0012*	−0.0012*	−0.0008		−0.0013**	−0.0014**	−0.0010	
	(0.0007)	(0.0007)	(0.0008)		(0.0007)	(0.0007)	(0.0008)	
Developed_rate	0.0190***	0.0206***	0.0174***		0.0199***	0.0216***	0.0184***	
	(0.0036)	(0.0037)	(0.0040)		(0.0036)	(0.0037)	(0.0040)	
Neighboring business rate		0.0209	0.0235			0.0189	0.0213	
		(0.0180)	(0.0185)			(0.0181)	(0.0186)	
Neighboring residence rate		−0.0163	−0.0135			−0.0140	−0.0121	
		(0.0261)	(0.0270)			(0.0261)	(0.0271)	
Neighboring undeveloped rate		−0.0093***	−0.0092**			−0.0091**	−0.0090**	
		(0.0036)	(0.0036)			(0.0036)	(0.0036)	
Neighboring developed rate		0.0265	0.0221			0.0256	0.0218	
		(0.0175)	(0.0179)			(0.0175)	(0.0180)	
log(Income tax)			−0.0809*	−0.0675*			−0.0782*	−0.0646
			(0.0418)	(0.0396)			(0.0419)	(0.0397)
log(Population)			0.1595***	0.1365***			0.1578***	0.1344***
			(0.0502)	(0.0486)			(0.0502)	(0.0487)
Percentage_Young			1.6882**	2.3872***			1.7247**	2.4970***
			(0.8186)	(0.7584)			(0.8201)	(0.7598)
Percentage_Older			1.5680***	2.1298***			1.5721***	2.1732***
			(0.4996)	(0.4722)			(0.5005)	(0.4730)
Unemployment			−1.4196***	−1.7146***			−1.4269***	−1.7025***
			(0.4305)	(0.4022)			(0.4313)	(0.4029)
Right			−0.0137	−0.0250			−0.0164	−0.0266
			(0.0185)	(0.0173)			(0.0185)	(0.0173)
Scrapping_1994			0.0119	0.0215			0.0124	0.0217
			(0.0313)	(0.0312)			(0.0314)	(0.0313)
Scrapping_1995			0.0170	0.0202			0.0173	0.0208
			(0.0311)	(0.0309)			(0.0311)	(0.0310)
Scrapping_1996			−0.1035	−0.1463**			−0.1054	−0.1533**
			(0.0645)	(0.0602)			(0.0646)	(0.0604)
Schedule			0.0185	0.0189			0.0190	0.0190
			(0.0164)	(0.0163)			(0.0164)	(0.0164)
Note:								*p<0.1; **p<0.05; ***p<0.01

1.8.3 Appendix A3: Estimation results integrating time fixed effects

Table 1.7: SAR regression with time fixed effects

	Dependent variable:Road tax							
	Time fixed effects				Both individual and time fixed effects			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
lambda	0.2956***	0.2970***	0.2974***	0.2973***	0.2990***	0.3006***	0.3008***	0.3006***
	(0.0160)	(0.0160)	(0.0160)	(0.0160)	(0.0160)	(0.0160)	(0.0160)	(0.0160)
Business_rate	0.0131**	0.0114**	0.0116**		0.0132**	0.0113**	0.0108*	
	(0.0053)	(0.0054)	(0.0057)		(0.0053)	(0.0053)	(0.0057)	
Residence_rate	−0.0204**	−0.0186**	−0.0183*		−0.0212**	−0.0200**	−0.0188*	
	(0.0089)	(0.0094)	(0.0098)		(0.0089)	(0.0094)	(0.0098)	
Undeveloped_rate	−0.0008	−0.0008	−0.0006		−0.0008	−0.0008	−0.0004	
	(0.0008)	(0.0008)	(0.0009)		(0.0008)	(0.0008)	(0.0009)	
Developed_rate	0.0145***	0.0166***	0.0179***		0.0143***	0.0164***	0.0179***	
	(0.0044)	(0.0045)	(0.0048)		(0.0043)	(0.0045)	(0.0048)	
W_business_rate_cont		0.0323	0.0392*			0.0321	0.0408*	
		(0.0212)	(0.0216)			(0.0211)	(0.0215)	
W_residence_rate_cont		0.0132	0.0083			0.0252	0.0184	
		(0.0314)	(0.0321)			(0.0318)	(0.0323)	
W_Undeveloped_rate_cont		−0.0129***	−0.0140***			−0.0125***	−0.0136***	
		(0.0040)	(0.0041)			(0.0040)	(0.0041)	
W_Developed_rate_cont		0.0118	0.0114			0.0057	0.0056	
		(0.0206)	(0.0210)			(0.0207)	(0.0211)	
log(Income_tax_cts)			−0.0939*	−0.1105**			−0.0832	−0.1050**
			(0.0503)	(0.0467)			(0.0506)	(0.0470)
log(Population)			0.1742***	0.1658***			0.1691***	0.1637***
			(0.0601)	(0.0572)			(0.0603)	(0.0576)
Percentage_Young			0.7082	1.3250			0.7010	1.2193
			(1.0119)	(0.9222)			(1.0232)	(0.9353)
Percentage_Older			0.9527	1.4569***			1.0458*	1.4923***
			(0.5860)	(0.5540)			(0.5899)	(0.5566)
Unemployment			−1.4647***	−1.2317***			−1.2809**	−1.1171**
			(0.5027)	(0.4745)			(0.5069)	(0.4780)
Note:								*p<0.1; **p<0.05; ***p<0.01

1.8.4 Appendix A4: Estimation results for each category of road tax sticker

Table 1.8: SAR Regression with contiguity matrix

	Tariff A				Tariff H				Tariff S			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
rho	0.7062***	0.5255***	0.3224***	0.4230***	0.6191***	0.5447***	0.3349***	0.4141***	0.4751***	0.3173***	0.2260***	0.2966***
	(0.0164)	(0.0233)	(0.0283)	(0.0261)	(0.0204)	(0.0233)	(0.0279)	(0.0266)	(0.0259)	(0.0310)	(0.0335)	(0.0320)
log(Stickers_5years)†	0.0262***	0.0342***	0.0030	−0.0157								
	(0.0085)	(0.0085)	(0.0095)	(0.0099)								
log(Stickers_5_20years)†					0.1119***	0.0397**	−0.0086	0.0353**				
					(0.0129)	(0.0163)	(0.0181)	(0.0177)				
log(Stickers_20years)†									0.0641***	0.0283**	0.0011	0.0098
									(0.0117)	(0.0125)	(0.0140)	(0.0142)
Business_rate†	0.0007	−0.0017	−0.0025*		0.0009	−0.0014	−0.0025**		0.0011	−0.0032	−0.0050*	
	(0.0013)	(0.0013)	(0.0013)		(0.0013)	(0.0013)	(0.0013)		(0.0025)	(0.0026)	(0.0026)	
Residence_rate†	0.0323***	0.0249***	0.0279***		0.0261***	0.0231***	0.0275***		0.0345***	0.0230***	0.0260***	
	(0.0038)	(0.0038)	(0.0036)		(0.0038)	(0.0037)	(0.0036)		(0.0073)	(0.0072)	(0.0072)	
Undeveloped_rate†	−0.0011*	−0.0010	0.00004		−0.0009	−0.0009	0.00002		−0.0012	−0.0004	0.0008	
	(0.0006)	(0.0006)	(0.0006)		(0.0006)	(0.0006)	(0.0006)		(0.0012)	(0.0012)	(0.0011)	
Developed_rate†	0.0066**	0.0068**	0.0019		0.0061**	0.0075***	0.0026		0.0155***	0.0129**	0.0063	
	(0.0027)	(0.0027)	(0.0026)		(0.0027)	(0.0026)	(0.0026)		(0.0052)	(0.0051)	(0.0052)	
W_Business_rate†		0.0265***	0.0238***			0.0256***	0.0248***			0.0313***	0.0283***	
		(0.0032)	(0.0031)			(0.0031)	(0.0030)			(0.0060)	(0.0060)	
W_Residence_rate†		0.0370***	0.0126			0.0290***	0.0112			0.0501***	0.0213	
		(0.0086)	(0.0086)			(0.0086)	(0.0084)			(0.0162)	(0.0168)	
W_Undeveloped_rate†		0.0001	0.0010			−0.0008	0.0002			0.0041	0.0056**	
		(0.0014)	(0.0013)			(0.0013)	(0.0013)			(0.0026)	(0.0026)	
W_Developed_rate†		−0.0077	−0.0162**			−0.0065	−0.0155**			−0.0120	−0.0222*	
		(0.0068)	(0.0066)			(0.0067)	(0.0064)			(0.0130)	(0.0130)	
log(Income_tax)†			0.0007	−0.0154			−0.0048	−0.0236			−0.0249	−0.0713**
			(0.0173)	(0.0177)			(0.0163)	(0.0168)			(0.0330)	(0.0326)
log(Population)			0.2172***	0.2636***			0.2424***	0.1920***			0.1825	0.2919***
			(0.0586)	(0.0578)			(0.0613)	(0.0643)			(0.1177)	(0.1132)
Percentage_Young			−2.8198***	−2.4796***			−2.8633***	−2.3553***			−2.5664***	−2.5749***
			(0.3624)	(0.3689)			(0.3539)	(0.3636)			(0.7070)	(0.6923)
Percentage_Older			1.3652***	2.6143***			1.3749***	2.3314***			1.1696*	3.1094***
			(0.3528)	(0.3328)			(0.3481)	(0.3457)			(0.6959)	(0.6322)
Unemployment			0.8418***	1.1859***			0.8517***	1.1295***			0.7209**	1.2475***
			(0.1523)	(0.1589)			(0.1485)	(0.1572)			(0.2954)	(0.2940)
Right			0.0122**	0.0039			0.0136**	0.0064			0.0087	−0.0023
			(0.0062)	(0.0065)			(0.0060)	(0.0064)			(0.0121)	(0.0124)
Scrapping_1994			0.0094*	0.0002			0.0084*	0.0009			0.0188*	0.0015
			(0.0050)	(0.0052)			(0.0049)	(0.0052)			(0.0098)	(0.0098)
Scrapping_1995			0.0148***	0.0079			0.0152***	0.0108**			0.0244***	0.0160*
			(0.0049)	(0.0051)			(0.0047)	(0.0049)			(0.0095)	(0.0096)
Scrapping_1996			0.2191***	0.1904***			0.2219***	0.1828***			0.2098***	0.2057***
			(0.0269)	(0.0274)			(0.0263)	(0.0269)			(0.0523)	(0.0512)

Note: *p<0.1; **p<0.05; ***p<0.01
Standard errors in parentheses.
† delayed variables from one period.

Table 1.9: Impact measures with contiguity weights matrix for SAR model

	Tariff A				Tariff H				Tariff S			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Direct												
log(Stickers_5years)†	0.0310***	0.0369***	0.00307	-0.0165								
log(Stickers_5_200years)†					0.1257***	0.0432**	-0.00893	0.0369**				
log(Stickers_20years)†									0.0681***	0.0289**	0.0011	0.010
Business_rate†	0.00077	-0.0003	-0.0015		0.0017	-0.00001	-0.0015		0.0012	0.0004	0.0036	
Residence_rate†	0.0382***	0.0368	0.0305		0.02937***	0.0288	0.0300		0.0367***	0.0347	0.0301	
Undeveloped_rate†	-0.0013	-0.0012	0.0004		-0.001	-0.0009	0.0004		-0.0013	-0.0012	0.0012	
Developed_rate†	0.0078**	0.0084	0.0002		0.0069**	0.0074	0.0010		0.0164***	0.0169	0.0039	
log(Income_tax)†			0.0007	-0.0161			-0.005	-0.0246			-0.0251	-0.0728**
log(Population)			0.2225***	0.2758***			0.2489***	0.2004***			0.1846	0.2979***
Percentage_Young			-2.8899***	-2.5943***			-2.94087***	-2.4589***			-2.5959***	-2.6281***
Percentage_Older			1.3991***	2.7352***			1.4121***	2.4339***			1.1831*	3.1737***
Unemployment			0.8627***	1.2408***			0.8748***	1.1792***			0.7292**	1.2733***
Right			0.0013**	0.0041			0.0140**	0.0066			0.0088	-0.0023
Scrapping_1994			0.0097**	0.0002			0.0086*	0.001			0.0190*	0.0016
Scrapping_1995			0.0151***	0.0082			0.0156***	0.0113**			0.0247	0.0164
Scrapping_1996			0.2245***	0.1992***			0.2279***	0.1908***			0.2122***	0.2099***
Indirect												
log(Stickers_5years)†	0.05818***	0.0352***	0.0014	-0.0108								
log(Stickers_5_20years)†					0.1682***	0.0441**	-0.0041	0.0234*				
log(Stickers_20years)†									0.0541***	0.0125**	0.0003	0.0039
Business_rate†	0.0014	-0.0069	-0.0037		0.0014	-0.0058	-0.0043		0.0009	-0.0037	-0.0033	
Residence_rate†	0.0717***	0.0956***	0.0427***		0.03925***	0.0629***	0.0440***		0.0292***	0.0461***	0.0339***	
Undeveloped_rate†	-0.0024	-0.0022	0.0026***		-0.0013	-0.0014	0.0026***		-0.0010	-0.0018	0.0056***	
Developed_rate†	0.0146**	0.0286	0.0042		0.0092**	0.0208*	0.0054		0.0131***	0.0325***	0.0116***	
log(Income_tax)†			0.0003	-0.0105			-2.3031	-0.0156			-0.007	-0.0286*
log(Population)			0.0979***	0.1811***			0.1155***	0.1272***			0.0512	0.1170**
Percentage_Young			-1.2716***	-1.703***			-1.3641***	-1.5609***			-0.7197***	-1.0324***
Percentage_Older			0.6156***	1.7956***			0.655***	1.5451***			0.328	1.2467***
Unemployment			0.3796***	0.8145***			0.4058***	0.7485***			0.2022**	0.5002***
Right			0.00550*	0.0027			0.0065**	0.0042			0.0024	-0.0009
Scrapping_1994			0.0043**	0.0001			0.004*	0.0006			0.0053*	0.0006
Scrapping_1995			0.0067***	0.0054			0.0072***	0.0072**			0.0068	0.0064
Scrapping_1996			0.0988***	0.1307***			0.1057***	0.1211***			0.0588***	0.0824***
Total												
log(Stickers_5years)†	0.0892***	0.0722***	0.0044	-0.0273								
log(Stickers_5_20years)†					0.2938***	0.0872**	-0.013	0.0603*				
log(Stickers_20years)†									0.1222***	0.0414**	0.0014	0.0139
Business_rate†	0.0022	-0.0072	-0.0053		0.0024	-0.0057	-0.0058		0.0021	-0.0033	-0.0069	
Residence_rate†	0.1099***	0.0953	0.0412		0.0685***	0.0629	0.0425		0.0658***	0.0464	0.0303	
Undeveloped_rate†	-0.0037	-0.0025	0.0011		-0.0023	-0.0014	0.0011		-0.0024	-0.0014	0.0020	
Developed_rate†	0.0224**	0.0283	0.0026		0.0161**	0.0208	0.0039		0.0295***	0.0329	0.0080	
log(Income_tax)†			0.0010	-0.0266			-0.0073	-0.0403			-0.0321	-0.1014**
log(Population)			0.3204***	0.4569***			0.3644***	0.3276***			0.2358	0.415***
Percentage_Young			-4.161***	-4.2973***			-4.3049***	-4.0198***			-3.3156***	-3.660***
Percentage_Older			2.0148***	4.5308***			2.0671***	3.9790***			1.5111*	4.420***
Unemployment			1.2424***	2.0553***			1.2805***	1.9277***			0.9314**	1.7735***
Right			0.01805**	0.0068			0.0204**	0.0108			0.0113	-0.0033
Scrapping_1994			0.0139**	0.0004			0.0126*	0.0016			0.0316*	0.0022
Scrapping_1995			0.0218***	0.0137			0.0228***	0.0184**			0.0315	0.0228
Scrapping_1996			0.3233***	0.3299***			0.3336***	0.3120***			0.2710***	0.2924***

Note: *p<0.1; **p<0.05; ***p<0.01
† delayed variables from one period.

Table 1.10: SAR regression with 5 nearest neighbors

	Tariff A				Tariff H				Tariff S			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
rho	0.7270***	0.5454***	0.3205***	0.4310***	0.6478***	0.5736***	0.3445***	0.4303***	0.4874***	0.3125***	0.2074***	0.2897***
	(0.0158)	(0.0236)	(0.0296)	(0.0271)	(0.0201)	(0.0233)	(0.0291)	(0.0276)	(0.0268)	(0.0331)	(0.0363)	(0.0344)
log(Stickers_5years)†	0.0254***	0.0343***	0.0038	−0.0155								
	(0.0086)	(0.0085)	(0.0096)	(0.0100)								
log(Stickers_5_20years)†					0.1017***	0.0308*	−0.0111	0.0319*				
					(0.0132)	(0.0165)	(0.0183)	(0.0178)				
log(Stickers_20years)†									0.0633***	0.0285**	0.0012	0.0094
									(0.0120)	(0.0126)	(0.0141)	(0.0143)
Business_rate†	0.0005	−0.0020	−0.0027**		0.0007	−0.0018	−0.0027**		0.0011	−0.0033	−0.0051**	
	(0.0013)	(0.0014)	(0.0013)		(0.0013)	(0.0013)	(0.0013)		(0.0026)	(0.0026)	(0.0026)	
Residence_rate†	0.0320***	0.0248***	0.0280***		0.0262***	0.0229***	0.0274***		0.0339***	0.0225***	0.0259***	
	(0.0038)	(0.0038)	(0.0037)		(0.0038)	(0.0037)	(0.0036)		(0.0073)	(0.0072)	(0.0072)	
Undeveloped_rate†	−0.0008	−0.0008	0.0001		−0.0007	−0.0008	0.0001		−0.0012	−0.0005	0.0009	
	(0.0006)	(0.0006)	(0.0006)		(0.0006)	(0.0006)	(0.0006)		(0.0012)	(0.0012)	(0.0012)	
Developed_rate†	0.0055**	0.0063**	0.0016		0.0054**	0.0070***	0.0024		0.0154***	0.0130**	0.0063	
	(0.0028)	(0.0027)	(0.0027)		(0.0027)	(0.0027)	(0.0026)		(0.0052)	(0.0052)	(0.0052)	
W_Business_rate†		0.0282***	0.0250***			0.0273***	0.0259***			0.0329***	0.0295***	
		(0.0032)	(0.0031)			(0.0031)	(0.0030)			(0.0060)	(0.0060)	
W_Residence_rate†		0.0335***	0.0116			0.0265***	0.0103			0.0515***	0.0227	
		(0.0087)	(0.0086)			(0.0087)	(0.0085)			(0.0163)	(0.0169)	
W_Undeveloped_rate†		−0.0002	0.0008			−0.0011	0.00003			0.0040	0.0056**	
		(0.0014)	(0.0014)			(0.0014)	(0.0013)			(0.0027)	(0.0027)	
W_Developed_rate†		−0.0068	−0.0156**			−0.0058	−0.0150**			−0.0125	−0.0229*	
		(0.0069)	(0.0066)			(0.0067)	(0.0065)			(0.0131)	(0.0130)	
log(Income_tax)†			0.0013	−0.0133			−0.0045	−0.0221			−0.0223	−0.0683**
			(0.0174)	(0.0179)			(0.0164)	(0.0170)			(0.0332)	(0.0328)
log(Population)			0.2127***	0.2536***			0.2348***	0.1814***			0.1757	0.2830**
			(0.0590)	(0.0584)			(0.0615)	(0.0646)			(0.1183)	(0.1140)
Percentage_Young			−2.8141***	−2.4411***			−2.8244***	−2.3070***			−2.6389***	−2.6445***
			(0.3662)	(0.3725)			(0.3565)	(0.3660)			(0.7121)	(0.6979)
Percentage_Older			1.3975***	2.6172***			1.3872***	2.3181***			1.2184*	3.1525***
			(0.3563)	(0.3392)			(0.3502)	(0.3498)			(0.6999)	(0.6392)
Unemployment			0.8738***	1.2154***			0.8795***	1.1576***			0.7678***	1.2897***
			(0.1543)	(0.1619)			(0.1500)	(0.1595)			(0.2976)	(0.2971)
Right			0.0123**	0.0042			0.0135**	0.0063			0.0083	−0.0030
			(0.0062)	(0.0066)			(0.0061)	(0.0064)			(0.0122)	(0.0125)
Scrapping_1994			0.0100**	0.0009			0.0087*	0.0014			0.0197**	0.0025
			(0.0051)	(0.0052)			(0.0050)	(0.0052)			(0.0098)	(0.0098)
Scrapping_1995			0.0155***	0.0086*			0.0155***	0.0112**			0.0255***	0.0171*
			(0.0049)	(0.0052)			(0.0047)	(0.0050)			(0.0095)	(0.0097)
Scrapping_1996			0.2193***	0.1882***			0.2195***	0.1796***			0.2160***	0.2116***
			(0.0272)	(0.0277)			(0.0265)	(0.0271)			(0.0527)	(0.0517)

Note: *p<0.1; **p<0.05; ***p<0.01
Standard errors in parentheses.
† delayed variables from one period.

Table 1.11: Impact measures with 5 nearest neighbors as weights matrix for SAR model

	Tariff A				Tariff H				Tariff S			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Direct												
log(Stickers_5years)†	0.0372***	0.03055***	0.0038	-0.0162								
log(Stickers_5_20years)†					0.0339**	0.116***	-0.011	0.0334*				
log(Stickers_20years)†									0.0291**	0.0674***	0.0012	0.0096
Business_rate†	-0.0022	-0.0004	-0.0015		-0.0020	0.0002	-0.0016		-0.0034	0.0004	-0.0036	
Residence_rate†	0.0270***	0.0367	0.0308		0.0252***	0.0290	0.0301		0.0231***	0.0340	0.0301	
Undeveloped_rate†	-0.0009	-0.0009	0.0005		-0.0009	-0.0007	0.0005		-0.0005	-0.0012	0.0012	
Developed_rate†	0.0068**	0.0073	-0.0003		0.0077***	0.0068	0.0006		0.0133**	0.0168	0.0037	
log(Income_tax)†			0.0013	-0.0139			-0.0046	-0.0232			-0.0225	-0.0697**
log(Population)			0.2179***	0.2658***			0.2416***	0.1902***			0.1773	0.2886***
Percentage_Young			-2.8831***	2.559***			-2.9058***	-2.4182***			-2.6642***	-2.6965***
Percentage_Older			1.4318***	2.7438***			1.4272***	2.4298***			1.230*	3.2145***
Unemployment			0.8952***	1.2741***			0.9048***	1.2134***			0.7752**	1.3151***
Right			0.0126**	0.0044			0.0139**	0.0066			0.0084	-0.003
Scrapping_1994			0.0102**	0.001			0.0089*	0.0014			0.01993*	0.00251
Scrapping_1995			0.0159***	0.0091			0.0159***	0.0118**			0.0257***	0.0174*
Scrapping_1996			0.2247***	0.1973***			0.2258***	0.1883***			0.2181***	0.2158***
Indirect												
log(Stickers_5years)†	0.0381***	0.0625***	0.0017	-0.011								
log(Sticker_5_20years)†					0.0384**	0.173***	-0.0055	0.0225*				
log(Sticker_20years)†									0.0123*	0.0561***	0.0003	0.0036
Business_rate†	-0.0022	-0.0066	-0.0036		-0.0023	-0.0061	-0.0042		-0.0014	0.0033	-0.0030	
Residence_rate†	0.0277***	0.0992***	0.0425***		0.0286***	0.0661***	0.0439***		0.0097***	0.0458***	0.0334***	
Undeveloped_rate†	-0.0009	-0.0012	0.0028***		-0.0010	-0.0008	0.0028***		-0.0002	-0.0018	0.0057***	
Developed_rate†	0.0070**	0.0266	0.0033		0.0088***	0.0209	0.0049		0.0056**	0.0322***	0.0109**	
log(Income_tax)†			0.00056	-0.0094			-0.0022	-0.0157			-0.0056	-0.0265*
log(Population)			0.0951***	0.1798***			0.1166***	0.1283**			0.0443	0.1099**
Percentage_Young			-1.2584***	-1.731***			-1.403***	-1.6317***			-0.6652***	-1.0267***
Percentage_Older			0.625***	1.8557***			0.6890***	1.6395***			0.3071	1.2240***
Unemployment			0.3907***	0.8618***			0.4368***	0.8187***			0.1936**	0.5008***
Right			0.0055**	0.0029			0.00672**	0.0045			0.0021	-0.0012
Scrapping_1994			0.0445**	0.0007			0.00432*	0.001			0.00498*	0.001
Scrapping_1995			0.0069***	0.0061			0.0077***	0.0079**			0.0064**	0.0066*
Scrapping_1996			0.0981***	0.1334***			0.109***	0.127***			0.0544***	0.0822***
Total												
log(Stickers_5years)†	0.0754***	0.0931***	0.0055	-0.0272								
log(Sticker_5_20years)†					0.0724**	0.2888***	-0.0169	0.0559*				
log(Sticker_20years)†									0.04139**	0.1235***	0.0014	0.0132
Business_rate†	-0.0044	-0.0070	-0.0051		-0.0042	0.0063	-0.0058		-0.0048	-0.0029	-0.0066	
Residence_rate†	0.0547***	0.0988	0.0410		0.0538***	0.0659	0.0423		0.0328***	0.0463	0.0298	
Undeveloped_rate†	-0.0018	-0.0016	0.0013		-0.0019	-0.0011	0.0012		-0.0007	-0.0013	0.0021	
Developed_rate†	0.0139**	0.0262	0.0018		0.0165***	0.0206	0.0033		0.0189**	0.0326	0.0073	
log(Income_tax)†			0.0018	-0.0234			-0.0068	-0.0389			-0.0282	-0.0962**
log(Population)			0.3131***	0.4456***			0.358***	0.3185***			0.2216	0.3985***
Percentage_Young			-4.1416***	-4.2899***			-4.3088***	-4.0499***			-3.3294***	-3.7232***
Percentage_Older			2.0567***	4.5995***			2.1163***	4.0693***			1.5372*	4.4386***
Unemployment			1.286***	2.1359***			1.3416***	2.0321***			0.9688**	1.81584***
Right			0.0182**	0.0073			0.0206**	0.0111			0.0104	-0.0042
Scrapping_1994			0.01465**	0.0017			0.0133*	0.0024			0.0249*	0.0035
Scrapping_1995			0.0228***	0.0151			0.0237***	0.0197**			0.0321**	0.0240*
Scrapping_1996			0.3228***	0.3307***			0.3348***	0.31535***			0.2725***	0.2979***

Note: *p<0.1; **p<0.05; ***p<0.01
† delayed variables from one period.

Chapter 2

Architecture of energy fiscal federalism

Abstract

The purpose of this study is to analyze tax interactions among two-tier governments, composed of several regional governments and a federal government. All of them can tax two tax bases, i.e. capital and an energy resource, that are interdependent. We find that the federal trade-off between the taxation of capital versus the taxation of energy only depends on the relative exogenous supply of energy and capital. The trade-off between the taxation of capital versus the taxation of energy is much more complex as it also depends on the comparison between distortive effects of these taxes on both the regional public good and the environmental quality, as well as on the interdependence between the two taxes. We also find a substitutability among federal and regional taxes, whatever the interdependence between the two taxes, implying that the federal government increases a given tax rate in response to a decrease of one of the two regional tax rates.

2.1 Introduction

It is important to develop efficient environmental policies to mitigate climate change, preserve biodiversity, and reduce water and air pollution. To this end, the public authorities have a wide range of instruments that are generally regulatory (conventional instruments, aimed at constraining agents' behavior) or economic ones (an incentive to encourage more virtuous behavior). Environmental taxation appears to be a less coercive tool than the norm, and nevertheless efficient when it allows economically to favor for sustainable behavior as compared to harmful behaviors to the environment. Thus, taxation is nowadays recognized as a powerful lever for modifying individual and collective behavior, owing to the financial incentive it addresses to those who support it.

Furthermore, energy taxation is being mutation in sense that fiscal decisions become increasingly centralized. For instance, in a Community framework, the EU has set drastic energy policy targets, including a 20% reduction in greenhouse gas emissions by 2020 and an increase of 20% of the share of renewable energies in gross final energy consumption. However member states remain sovereign in terms of energy resources and way to achieve the objectives set by Europe. For illustration, it is important to emphasize that energy policy for most European countries has at least three distinct levels of decision: the European Union, the State and local authorities. Therefore, while energy transition is increasingly defined at the upper tier (e.g. European level), the actors involved in its implementation will be increasingly decentralized and close to consumers. In addition, energy resources are various forms and dispersed in space. Hence, their exploitation modifies the geographical distribution of energy potentials.

Related to energy resources, at least two main implications are essentials when implementing energy fiscal policy: there are fiscal and environmental considerations. From fiscal considerations, the concentration of energy resources in certain localities may lead to fiscal disparities between local authorities. Local governments can compete both in terms of fiscal point of view and provision of public services in order to attract mobile production factors. To alleviate these fiscal distortions, central or federal government can levy a federal tax in order to reduce the magnitude of intergovernmental fiscal disparities. Indeed, it is well-known that heterogeneity of energy fiscal endowments can lead to significant fiscal disparities. For illustration, the problematic of fiscal disparities between regions is particularly important in large countries which produce natural resources such as Canada (oil, natural gas, uranium, diamonds, gold, nickel), Australia (coal, uranium, iron, potash, Bauxite) and Russia (natural gas, oil, coal, uranium, aluminum, nickel). In these three federations, the natural resource rent is owned by the regional entities. From an environmental point of view, the exploitation of energy resources can cause significant environmental damage. In this perspective, environmental taxation has attracted increasing attention as taxes can, at least in principle, internalize the external effects of environmental damage. Furthermore, many economists have argued that environmental taxes are an efficient instrument for achieving environmental objectives (see, e.g, Baumol and Oates (1988) and Pearce and Turner (1990)).

Furthermore, even if high attention has turned to the key feature of the energy transition, however from a normative point of view, there are few contributions on "energy fiscal federalism" defined as the imbrication of different levels of government which possess an autonomous power to tax energy. And yet, there are numerous issues. Should the Member States levy alone the energy tax? What would be the effectiveness of an additional energy tax levied on a larger scale at European level? Is it desirable for fiscal policy to be fully transferred to a central level (Brussels in a Community framework, or the central State in the framework of a country) or contrarily, should be given priority to the decentralization of energy tax policy to sub-national communities in order to better account for heterogeneity among jurisdictions, in particular in terms of energy access? Should the distribution of energy taxation instruments depend on the nature of energies? These questions are then asked to determine which level of government should levy what energy taxation. Decentralization of energy taxation should be analyzed in the light of these mechanisms, taking into account the specificities of the bases of energy resources: the environmental consequences of the exploitation of energy, the more or less renewable nature of energy, their (sometimes immediate) impacts on economic growth, the greater or lesser substitutability between the bases or the globalization of energy markets.

In this study, we consider a two-tier territorial organization with several identical bottom-tier jurisdictions, such as region, and a unique top-tier jurisdiction, such as the federal government. Breuillé and Duran-Vigneron (2018), we extend the standard model of fiscal federalism developed by Keen and Kotsogiannis (2002), Keen and Kotsogiannis (2004) who consider one tax base, namely the capital, by incorporating an additional tax base, both tax bases being interdependent. The originality is that the tax base is energy, which has an impact on the provision of an environmental public good, namely "environmental quality", which depends negatively to energy consumption. The federal and regional governments tax the same mobile bases, that are the amounts of capital and energy invested in their territory. As a consequence, both tax bases are co-occupied. Benevolent federal and regional governments use their tax revenues in order to finance public goods that benefit exclusively their immobile inhabitants. Finally, we assume that the federal and regional governments use taxes as their strategy variables in a simultaneous-move Nash game.

Three main results emerge from our paper. We find that the federal trade-off between the taxation of capital versus the taxation of energy only depends on the relative exogenous supply of energy and capital. The regional trade-off between the taxation of capital versus the taxation of energy is much more complex as it also depends on the comparison between the distortive effects of these taxes on both the regional public good and the environmental quality, as well as on the interdependence between the two taxes. We also find a substitutability among federal and regional taxes, whatever the interdependence between the two taxes, implying that the federal government increases a given tax rate in response to a decrease of one of the two regional tax rates.

The present chapter thus contributes to the theoretical literature in two ways. First, it provides additional comprehension elements on the issue of energy fiscal federalism by examining the structure of energy taxes levied by two tiers aimed at internalizing the external effects from environmental damage. Second, it extends earlier analytical work on optimal energy taxation in the presence of other distortionary tax by considering that energy tax is imposed on intermediate inputs for improving environmental quality.

The paper is organized as follows. Section 2 presents a brief literature review. In Section 3, we derive optimal taxes and tax reaction functions in the Nash game played by federal and regional players. Finally, in Section 4, we provide concluding comments.

2.2 Literature review

2.2.1 Fiscal federalism literature

Several studies have emphasized the importance of tax externalities (horizontal and vertical) for the theory of fiscal federalism. Initially developed by Oates Wallace (1972) and formally modelled by Wilson (1986) and Zodrow and Mieszkowski (1986), the existence of tax externalities depends on the mobility of tax base. In particular, in presence of horizontal tax externalities, when a region increases its capital tax rate, some amount of the tax base (usually capital) is reallocated to other regions. This reallocation represents a positive externality, which is not taken into account, implying that taxes and public expenditures are inefficiency low in equilibrium. The literature has paid a recent attention on vertical tax externalities, which arise when two or more different levels of government share the same tax base. Each level of government neglects the adverse effect it has on the other by raising its tax rate. Vertical tax externalities lead to excessively high taxes

(Dahlby and Wilson, 2003; Hoyt, 2001; Keen, 1998; Keen and Kotsogiannis, 2002). With horizontal externalities pointing towards regional taxes that are inefficiently low and vertical externalities towards regional taxes that are inefficiently high, it is natural to ask which will dominate. Keen and Kotsogiannis (2002), show that whether equilibrium taxes are too high or too low in equilibrium depends on the elasticities of the demand for capital and the supply of savings.

Breuillé and Duran-Vigneron (2018) consider two interdependent tax bases, which creates indirect horizontal and vertical tax externalities, in addition to standard direct horizontal and vertical tax externalities. We will retain this framework in this chapter.

2.2.2 Literature about environmental taxation

Generally, an emission tax is used as an environmental policy instrument to reduce local environmental damages. The rents raised from this tax are retained locally, but can be allocated to varying degrees for public finance or for private consumption. In this regard, Alexeev et al. (2016) explore the implications for jurisdictional welfare of sharing environmental rents between private and public consumption. Using three production factor (labor, capital and emissions), they show that jurisdictional welfare increases as environmental rents are initially allocated towards public consumption, yielding a "double dividend", in the sense that welfare of jurisdictional decision-making is highest when all environmental rents are dedicated to public finance. These results illustrate the crucial importance of environmental rent sharing for the efficiency of jurisdictional decision-making.

Linked to the previous point, Kim and Wilson (1997) investigate the possibility of a 'race to the bottom,' under which intergovernmental competition for mobile capital leads to inefficiently lax environmental standards. The term 'race to the bottom' is often used to describe the possibility that intergovernmental competition for mobile capital will lead to inefficiently lax environmental policies. Their model is based on the Bucovetsky-Wilson model of tax competition with multiple tax instruments, extended to include pollution emissions from production activities. Indeed, in addition to capital and labor as input factors, they include emissions in production function. In particular, according to this input factor, they follow Oates and Schwab (1988), by making the emissions-labor ratio, $e = E/L$. They show that decentralized decision-making by independent national governments leads to environmental standards that are inefficiently lax.

According to Wellisch (1995), in the course of jurisdictional competition, jurisdictions set environmental policies efficiently if there are no other market distortions and the environmental policies capture and return environmental rents to local, immobile residents. A similar kind of result is obtained in the classic model of Oates and Schwab (1988). In the presence of other market dis-

[9] The double dividend hypothesis states that it is possible to improve the quality of the environment and the efficiency of the tax system. In other words the double dividend assumption implies that there would be environmental and non-environmental gains in the application of an environmental tax when revenues from the environmental tax are used to reduce a form of taxation that creates more distortions. In the literature, the double dividend is known into two forms: weak and strong forms. According to Goulder et al. (1999), the weak form states that it is cheaper to use green tax revenues to reduce a pre-existing distortionary tax than to redistribute those revenues into lump-sum transfers. The strong form implies that taxing a polluting good and recycling its revenues in order to reduce a representative distortionary tax does not entail any cost, or even brings income to the state.

tortions or if jurisdictions cannot capture the environmental rents, jurisdictional environmental policy-making is not likely to be efficient.

Bovenberg and De Mooij (1994) aim to explore under which conditions environmental taxes do indeed reduce the efficiency costs of financing public spending in presence of other distortion tax (in particular, labor tax). To this end, they formulate a simple general equilibrium model of a small open economy. Besides labor (L,) and capital (K), they also include in production function a third input (E) which causes environmental damage. It is called the "polluting" input and can be thought off as energy. In their model, they formalize an inverse relationship between the quality of the natural environment and the demand for, respectively, polluting consumption commodities and polluting inputs into production. They find that environmental taxes typically render the overall tax system a less efficient instrument to finance public spending. They also find that pre-existing tax distortions in the labor market reduce rather than enhance the attractiveness of environmental policy, in general, and of a heavy reliance on environmental taxes, in particular. The fundamental reason is that the environment is a collective good; all residents benefit - irrespective of the amount of labor they supply.

Bovenberg and Goulder (1996) extend the model in Bovenberg and De Mooij (1994) by incorporating intermediate inputs. They also consider three inputs in production function, namely, labor (L) , "clean" and "dirty" intermediate goods. They examine how optimal environmental tax rates deviate from rates implied by the Pigovian principle in a second-best setting where other, distortionary taxes are present. They show that, in the presence of distortionary taxes, optimal environmental tax rates are generally below the rates suggested by the Pigovian principle-even when revenues from environmental taxes are used to cut distortionary taxes. As mentioned in Bovenberg and Goulder (1996), economists typically have analyzed environmental taxes without taking into account the presence of other distortionary taxes. The omission is significant because the consequences of environmental taxes depend fundamentally on the levels of other taxes.

2.3 Model

2.3.1 Federal and regional governments

We assume a two-tier intergovernmental structure comprised of a federal government and n regional governments, indexed by $i = 1, ..., n$. Pure public goods are provided at both federal and regional tiers, with no spillovers and no scale economies. Each regional government i provides a regional public good in quantity g_i, which is financed by the taxation at the rate t_i of the amount of capital k_i invested in the region and the taxation at the rate τ_i of the amount of energy input e_i used in the region. The regional budget constraint is thus given by

$$g_i = t_i k_i + \tau_i e_i \tag{2.1}$$

The federal government provides publicly provided private goods in quantity nG, which are financed by respectively the taxation at rates T_k and T_e of the amount of capital $\sum_i k_i$ and energy $\sum_i e_i$ employed in region i. The federal budget constraint is thus given by:

$$G = \frac{T_k}{n}\sum_i k_i + \frac{T_e}{n}\sum_i e_i \tag{2.2}$$

We assume that both federal and regional governments are utilitarian and benevolent. Each jurisdiction acts so as to maximize the utility of its representative citizen.

2.3.2 Capital and energy markets

There is an unique immobile firm in each region. The firm located in region i produces an output $f(k_i, e_i)$ from the capital k_i borrowed on the market at the interest rate r_i^k and from the energy e_i borrowed on the market at the price r_i^e. The production function, which is identical across regions, is assumed to be monotonously increasing in both production factors with $f'[.] > 0$ and to have diminishing factor productivities $f''[.] < 0$. Capital and energy can be complementary inputs in production ($f_{ke} > 0$ and $f_{ek} > 0$) or competitive inputs ($f_{ke} < 0$ and $f_{ek} < 0$). We make the restrictive assumption that $f'''[.] = 0$ to ensure that the demands for capital and energy are linear, which makes it possible to derive closed form solutions. The owner of the firm is the representative citizen of the region, which receives the entire profit, which is standard in this type of model: $\pi_i = F(k_i, e_i) - (\rho_{k_i} + t_i + T_k)k_i - (\rho_{e_i} + \tau_i + T_e)e_i$.

For simplicity, we assume that the profit is not taxed. Since producers act as price takers, firm profit maximizing behavior implies the following first-order conditions system:

$$\begin{cases} f_{k_i} = r_i^k \\ f_{e_i} = r_i^e \end{cases}$$

which means that capital and energy are remunerated at their marginal productivities, with $r_i^k = \rho_{k_i} + t_i + T_k$ and $r_i^e = \rho_{e_i} + \tau_i + T_e$. The resulting demands for capital $k(r_i^k, r_i^e)$, energy $e(r_i^k, r_i^e)$ and the expression of the profit $\pi_i(r_i^k, r_i^e)$ are presented in Appendix A.

Capital and energy are both perfectly mobile in perfectly competitive markets. They move across regions until they earn the same net return everywhere, that are respectively, $\rho_k = r_i^k - (t_i + T_k)$ and $\rho_e = r_i^e - (\tau_i + T_e)\ \forall_i$. The representative citizen of each region i is initially endowed with $\bar{k}$ units of capital and $\bar{e}$ units of energy. The overall supply of capital is $n\bar{k}$ and the overall supply of energy is $n\bar{e}$. Given that $r_i^k = \rho_k + t_i + T_k$ and $r_i^e = \rho_e + \tau_i + T_e\ \forall_i$, the capital and energy market-clearing conditions are respectively $\sum_{i=1}^n k(\rho_k + t_i + T_k, \rho_e + \tau_i + T_e) = n\bar{k}$ and $\sum_{i=1}^n e(\rho_k + t_i + T_k, \rho_e + \tau_i + T_e) = n\bar{e}$, which implicitly define the equilibrium values of the net returns on capital and energy , $\rho_k(T_k, t_1, ..., t_i, ..., t_n)$, $\rho_e(T_e, \tau_1, ..., \tau_i, ..., \tau_n)$. Differentiating the markets-clearing conditions yields, at the symmetric equilibrium:

$\frac{d\rho_k}{dt_i} = \frac{d\rho_e}{d\tau_i} = \frac{-1}{n}$,
$\frac{d\rho_k}{dT_k} = \frac{d\rho_e}{dT_e} = -1$,

$\frac{d\rho_e}{dt_i} = \frac{d\rho_k}{d\tau_i} = \frac{d\rho_k}{dT_e} = \frac{d\rho_e}{dT_k} = 0,$
$\frac{dr_i^k}{dt_i} = 1 + \frac{d\rho_k}{dt_i} = \frac{n-1}{n}, \frac{dr_i^e}{d\tau_i} = 1 + \frac{d\rho_e}{d\tau_i} = \frac{n-1}{n},$
$\frac{dr_i^k}{dT_k} = \frac{dr_i^e}{dT_e} = \frac{dr_i^k}{dT_e} = \frac{dr_i^e}{dT_k} = 0$

The mobility of the two tax bases generate a double common-pool problem(Breuillé and Duran-Vigneron, 2018). The choice of a region's tax rate affects its own tax base, the tax base of other same-tier regions and the tax base of the federation, because of the combination of tax-base sharing and mobility. Due to the interdependence between the two tax bases, the choice of a region's tax rate on a given tax base also affects its other tax base, the other tax base of other same-tier regions and the other tax base of the federation. These indirect tax effects do not go through the returns as $\frac{d\rho_e}{dt_i} = \frac{d\rho_k}{d\tau_i} = \frac{d\rho_k}{dT_e} = \frac{d\rho_e}{dT_k} = 0$ but through the demand functions $k_i\left(r_i^k, r_i^e\right)$ and $e_i\left(r_i^k, r_i^e\right)$. In addition, it should be noted that contrary to regional tax choices that affect the gross return (r_i^k for capital and r_i^e for energy), federal choices have no impact on gross returns.

2.3.3 The representative citizen

Citizens are assumed to be identical and immobile, such that we consider a representative citizen in each jurisdiction. The representative citizen in a region i obtains utility $U(C_i, g_i, G, E_i)$ from the consumption of the regional public good g_i, the consumption of a the federal public good G as well as utility from the consumption of a private good C_i and an environmental public good, namely "environmental quality" denoted by E_i.[20] Environmental quality E_i is a regional good, which is defined as follow:

$$E_i = h(e_i) \tag{2.3}$$

with $h_{e_i} < 0$ which links up to energy resource. This expression formalizes the inverse relationship between the quality of the natural environment and the demand for energy inputs into production. We assume that energy consumption (e_i) harms environmental quality (E_i). Indeed, in the process of production, the use of energy input is associated with less environmental quality due to for instance a higher level of emissions. Following Bovenberg and Goulder (1996), we consider that environment quality is a collective good and weakly separable from private goods. Accordingly, households take the quality of the environment as given and they ignore the adverse effect of their demand for energy on the quality of the environment.

We assume that the representative citizen in region i is both the owner of a unique firm located in its jurisdiction and the owner of exogenous amounts $\overline{k}$ of capital and $\overline{e}$ of energy. The amount of each input ($\overline{k}$ and $\overline{e}$) can be invested in a firm in any region to earn the net return on capital (respectively on energy), denoted by ρ_{ki} (resp. ρ_{ei}), which is equal to the return after regional and federal taxes. As shown before, at the symmetric equilibrium, $\rho_{ki} = \rho_k$ and $\rho_{ei} = \rho_e$.

The private consumption is: $C_i = \pi_i + \rho_k\overline{k} + \rho_e\overline{e} = F(k_i, e_i) - (\rho_k + t_i + T_k)k_i - (\rho_e + \tau_i + T_e)e_i + \rho_k\overline{k} + \rho_e\overline{e}$.

[20] The composite good provided can be used for public consumption (G or g_i), for household consumption C_i, or environmental quality good E_i.

In order to derive explicit solutions for equilibrium tax rates, we need specific assumptions on the functional form of the utility function.

2.3.4 The timing of the game

In the benchmark case, the federal government and the n regional governments simultaneously select their fiscal parameters, taking as given the policy choices of the other players. In other words, federal and regional governments play a Nash game. More specifically, the federal government selects tax rates T_k and T_e to maximize the welfare of the representative citizen residing within the federation, taking as given tax rates chosen by the regional governments. Simultaneously, each regional government i selects its tax rates (t_i and τ_i) to maximize the welfare of the representative citizen residing within their jurisdiction, taking as given tax rates chosen by the federation and other regional jurisdictions. Federal and regional public goods are determined as residuals after taxes are collected. Given these policy choices, firms determine capital and energy demands, and then production takes place. Finally, each citizen receives profits from her firm's activity, enjoys the consumption of private, regional and federal public goods and derives utility from the quality of natural environment. Federal and regional jurisdictions take into account the reaction of the capital and energy demands when determining their tax decisions and citizens' preferences guide the choices of the federal and regional jurisdictions as they are both benevolent. These results are derived in the Nash game.

2.4 The Nash game

Before illustrating the subgame-perfect equilibrium, we first present the outcome of the first-best solution which will serve for comparison purposes. In this benchmark case, a benevolent social planner aims to maximize the aggregated welfare $W(t_i, \tau_i, T_k, T_e) = \sum_{i=1}^{n} U(C_i, g_i, G, E_i)$ subject to the budget constraints (1), (2) and (5). Suppose that federal and regional governments play a Nash game. In this situation, the federal government and regional governments simultaneously select their fiscal choices.

2.4.1 The federal government's problem

The federal government maximizes the aggregated utility of citizens located in the federation by choosing the tax rates T_k and T_e, taking as given the tax choices of regional jurisdictions. It thus solves the problem:

Max $W(t_i, \tau_i, T_k, T_e) = \sum_{i=1}^{n} U(C_i, g_i, G, E_i)$

subject to

$C_i = \pi_i + \rho_{k_i}\overline{k} + \rho_{e_i}\overline{e},$

$g_i = t_i k_i + \tau_i e_i,$

$G = \frac{T_k}{n}\sum_i k_i + \frac{T_e}{n}\sum_i e_i$.

The federal tax policy satisfies the following first-order conditions:

FOC $/T_k$: $\sum_{i=1}^n \left[\frac{\partial U}{\partial C_i}\frac{\partial C_i}{\partial T_k} + \frac{\partial U}{\partial g_i}\frac{\partial g_i}{\partial T_k} + \frac{\partial U}{\partial G}\frac{\partial G}{\partial T_k} + \frac{\partial U}{\partial E_i}\frac{\partial E_i}{\partial T_k}\right] = 0$,

FOC $/T_e$: $\sum_{i=1}^n \left[\frac{\partial U}{\partial C_i}\frac{\partial C_i}{\partial T_e} + \frac{\partial U}{\partial g_i}\frac{\partial g_i}{\partial T_e} + \frac{\partial U}{\partial G}\frac{\partial G}{\partial T_e} + \frac{\partial U}{\partial E_i}\frac{\partial E_i}{\partial T_e}\right] = 0$.

Using the expressions derived in the Appendix B, at the symmetric equilibrium, the FOCs boil down to:

$$\frac{\partial U}{\partial C_i} = \frac{\partial U}{\partial G}. \tag{2.4}$$

Since $\frac{\partial E_i}{\partial T_k} = \frac{\partial E_i}{\partial T_e} = 0$, the federal taxation has no impact on the environmental quality.

In a Nash game, the federal government thus chooses the vector of optimal taxes ($\widehat{T_k}$ and $\widehat{T_e}$) to equalize the marginal desutility from a reduction in private consumption to the marginal utility from an increase in the federal public good provision. Eq. (2.4) determines the federal government's reaction function $T_k(t_1, ..., t_i, ..., t_n, \tau_1, ..., \tau_i, ..., \tau_n, T_e)$ and $T_e(t_1, ..., t_i, ..., t_n, \tau_1, ..., \tau_i, ..., \tau_n, T_k)$.

Differentiating (2.4) w.r.t. federal tax rates and regional tax rates, we obtain that $\frac{\partial^2 U}{\partial C_i^2}\left(\frac{\partial C_i}{\partial T_k}dT_k + \frac{\partial C_i}{\partial T_e}dT_e + \frac{\partial C_i}{\partial t_i}dt_i + \frac{\partial C_i}{\partial \tau_i}d\tau_i\right) = \frac{\partial^2 U}{\partial G^2}\left(\frac{\partial G}{\partial T_k}dT_k + \frac{\partial G}{\partial T_e}dT_e + \frac{\partial G}{\partial t_i}dt_i + \frac{\partial G}{\partial \tau_i}d\tau_i\right)$, which gives

$$\begin{aligned}\frac{dT_k}{dT_e} &= \frac{dT_k}{d\tau_i} = -\frac{\overline{e}}{\overline{k}}\\ \frac{dT_k}{dt_i} &= \frac{dT_e}{d\tau_i} = -1\\ \frac{dT_e}{dT_k} &= \frac{dT_e}{dt_i} = -\frac{\overline{k}}{\overline{e}}\end{aligned}$$

at the symmetric equilibrium. The federal trade-off between the taxation of capital versus the taxation of energy depends on the relative endowment $\frac{\overline{e}}{\overline{k}}$. For $\overline{e} = \overline{k}$, $dT_k + dT_e = 0$. We also find a substitutability among federal and regional taxes, whatever the interdependence between the two taxes.

2.4.2 The regional government's problem

Each regional government i chooses its tax rates t_i and τ_i so as to maximize the utility of its representative citizen subject to the governmental budget constraints and the decentralized optimizing behavior of firms and households, taking as given the tax choices of federal and other jurisdictions. It thus solves the problem:

Max $W(t_i, \tau_i) = U(C_i, g_i, G, E_i)$

subject to

$C_i = \pi_i + \rho_{k_i}\overline{k} + \rho_{e_i}\overline{e}$,

$g_i = t_i k_i + \tau_i e_i$,

$G = \frac{T_k}{n}\sum_i k_i + \frac{T_e}{n}\sum_i e_i$.

The first-order conditions are:

FOC $/t_i$: $\frac{\partial U}{\partial C_i}\frac{\partial C_i}{\partial t_i} + \frac{\partial U}{\partial g_i}\frac{\partial g_i}{\partial t_i} + \frac{\partial U}{\partial G}\frac{\partial G}{\partial t_i} + \frac{\partial U}{\partial E_i}\frac{\partial E_i}{\partial t_i} = 0$

FOC $/\tau_i$: $\frac{\partial U}{\partial C_i}\frac{\partial C_i}{\partial \tau_i} + \frac{\partial U}{\partial g_i}\frac{\partial g_i}{\partial \tau_i} + \frac{\partial U}{\partial G}\frac{\partial G}{\partial \tau_i} + \frac{\partial U}{\partial E_i}\frac{\partial E_i}{\partial \tau_i} = 0$.

Using the expressions derived in the Appendix B, at the symmetric equilibrium, the FOCs boil down to:

$$\begin{cases} -\frac{\partial U}{\partial C_i}\overline{k} + \frac{\partial U}{\partial g_i}(k_i + t_i k_{r^k}\frac{\partial r_i^k}{\partial t_i} + \tau_i e_{r^k}\frac{\partial r_i^k}{\partial t_i}) + \frac{\partial U}{\partial E_i}\frac{\partial E_i}{\partial r_i^k}\frac{\partial r_i^k}{\partial t_i} = 0 \\ -\frac{\partial U}{\partial C_i}\overline{e} + \frac{\partial U}{\partial g_i}(e_i + t_i k_{r^e}\frac{\partial r_i^e}{\partial \tau_i} + \tau_i e_{r^e}\frac{\partial r_i^e}{\partial \tau_i}) + \frac{\partial U}{\partial E_i}\frac{\partial E_i}{\partial r_i^e}\frac{\partial r_i^e}{\partial \tau_i} = 0 \end{cases} \tag{2.5}$$

The system (2.5) determines the regional government's reaction functions $t_i(T_k, T_e, t_1, ..., t_{i-1}, t_{i+1}, ..., t_n, \tau_1, ..., \tau_i, ..., \tau_n)$ and $\tau_i(T_k, T_e, t_1, ..., t_i, ..., t_n, \tau_1, ..., \tau_{i-1}, \tau_{i+1}..., \tau_n)$. Differentiating (2.5) w.r.t. federal tax rates and regional tax rates, and using the expressions derived in the Appendix B, we obtain at the symmetric equilibrium that:

$$\begin{cases} -\frac{\partial^2 U}{\partial C_i^2}\overline{k}\left(-\overline{k}dT_k - \overline{e}dT_e - \overline{k}dt_i - \overline{e}d\tau_i\right) + \frac{\partial^2 U}{\partial g_i^2}\frac{\partial g_i}{\partial t_i}\left(\frac{\partial g_i}{\partial t_i}dt_i + \frac{\partial g_i}{\partial \tau_i}d\tau_i\right) + \frac{\partial U}{\partial g_i}\left(\frac{\partial^2 g_i}{\partial t_i^2}dt_i + \frac{\partial^2 g_i}{\partial t_i \partial \tau_i}d\tau_i\right) + \\ \qquad \frac{\partial^2 U}{\partial E_i^2}\frac{\partial E_i}{\partial t_i}\left(\frac{\partial E_i}{\partial t_i}dt_i + \frac{\partial E_i}{\partial \tau_i}d\tau_i\right) + \frac{\partial U}{\partial E_i}\left(\frac{\partial^2 E_i}{\partial t_i^2}dt_i + \frac{\partial^2 E_i}{\partial t_i \partial \tau_i}d\tau_i\right) = 0 \\ -\frac{\partial^2 U}{\partial C_i^2}\overline{e}\left(-\overline{k}dT_k - \overline{e}dT_e - \overline{k}dt_i - \overline{e}d\tau_i\right) + \frac{\partial^2 U}{\partial g_i^2}\frac{\partial g_i}{\partial \tau_i}\left(\frac{\partial g_i}{\partial t_i}dt_i + \frac{\partial g_i}{\partial \tau_i}d\tau_i\right) + \frac{\partial U}{\partial g_i}\left(\frac{\partial^2 g_i}{\partial \tau_i \partial t_i}dt_i + \frac{\partial^2 g_i}{\partial \tau_i^2}d\tau_i\right) + \\ \qquad \frac{\partial^2 U}{\partial E_i^2}\frac{\partial E_i}{\partial \tau_i}\left(\frac{\partial E_i}{\partial t_i}dt_i + \frac{\partial E_i}{\partial \tau_i}d\tau_i\right) + \frac{\partial U}{\partial E_i}\left(\frac{\partial^2 E_i}{\partial \tau_i \partial t_i}dt_i + \frac{\partial^2 E_i}{\partial \tau_i^2}d\tau_i\right) = 0 \end{cases}$$

Solving the system

$$\begin{cases} \left[\frac{\partial^2 U}{\partial C_i^2}\overline{k}^2 + \frac{\partial^2 U}{\partial g_i^2}\left(\frac{\partial g_i}{\partial t_i}\right)^2 + \frac{\partial U}{\partial g_i}\frac{\partial^2 g_i}{\partial t_i^2} + \frac{\partial^2 U}{\partial E_i^2}\left(\frac{\partial E_i}{\partial t_i}\right)^2 + \frac{\partial U}{\partial E_i}\frac{\partial^2 E_i}{\partial t_i^2}\right]dt_i + \\ \Bigg[\frac{\partial^2 U}{\partial C_i^2}\overline{k}\overline{e} + \frac{\partial^2 U}{\partial g_i^2}\frac{\partial g_i}{\partial t_i}\frac{\partial g_i}{\partial \tau_i} + \frac{\partial U}{\partial g_i}\frac{\partial^2 g_i}{\partial t_i \partial \tau_i} + \frac{\partial^2 U}{\partial E_i^2}\frac{\partial E_i}{\partial t_i}\frac{\partial E_i}{\partial \tau_i} + \frac{\partial U}{\partial E_i}\frac{\partial^2 E_i}{\partial t_i \partial \tau_i} \\ \frac{\partial^2 U}{\partial C_i^2}\overline{e}\overline{k} + \frac{\partial^2 U}{\partial g_i^2}\frac{\partial g_i}{\partial \tau_i}\frac{\partial g_i}{\partial t_i} + \frac{\partial U}{\partial g_i}\frac{\partial^2 g_i}{\partial \tau_i \partial t_i} + \frac{\partial^2 U}{\partial E_i^2}\frac{\partial E_i}{\partial \tau_i}\frac{\partial E_i}{\partial t_i} + \frac{\partial U}{\partial E_i}\frac{\partial^2 E_i}{\partial \tau_i \partial t_i}\Bigg]d\tau_i = \frac{\partial^2 U}{\partial C_i^2}\overline{k}\left(-\overline{k}dT_k - \overline{e}dT_e\right) \\ \\ \left[\frac{\partial^2 U}{\partial C_i^2}\overline{e}\overline{k} + \frac{\partial^2 U}{\partial g_i^2}\frac{\partial g_i}{\partial \tau_i}\frac{\partial g_i}{\partial t_i} + \frac{\partial U}{\partial g_i}\frac{\partial^2 g_i}{\partial \tau_i \partial t_i} + \frac{\partial^2 U}{\partial E_i^2}\frac{\partial E_i}{\partial \tau_i}\frac{\partial E_i}{\partial t_i} + \frac{\partial U}{\partial E_i}\frac{\partial^2 E_i}{\partial \tau_i \partial t_i}\right]dt_i + \\ \left[\frac{\partial^2 U}{\partial C_i^2}\overline{e}^2 + \frac{\partial^2 U}{\partial g_i^2}\left(\frac{\partial g_i}{\partial \tau_i}\right)^2 + \frac{\partial U}{\partial g_i}\frac{\partial^2 g_i}{\partial \tau_i^2} + \frac{\partial^2 U}{\partial E_i^2}\left(\frac{\partial E_i}{\partial \tau_i}\right)^2 + \frac{\partial U}{\partial E_i}\frac{\partial^2 E_i}{\partial \tau_i^2}\right]d\tau_i = \frac{\partial^2 U}{\partial C_i^2}\overline{e}\left(-\overline{k}dT_k - \overline{e}dT_e\right) \end{cases} \tag{2.6}$$

using a Cramer rule, we get:

$$\frac{dt_i}{dT_k} = \frac{1}{\det A} * \left[-\frac{\partial^2 U}{\partial C_i^2}\overline{k}^2 \left[\frac{\partial^2 U}{\partial C_i^2}\overline{e}^2 + \frac{\partial^2 U}{\partial g_i^2}\left(\frac{\partial g_i}{\partial \tau_i}\right)^2 + \frac{\partial U}{\partial g_i}\frac{\partial^2 g_i}{\partial \tau_i^2} + \frac{\partial^2 U}{\partial E_i^2}\left(\frac{\partial E_i}{\partial \tau_i}\right)^2 + \frac{\partial U}{\partial E_i}\frac{\partial^2 E_i}{\partial \tau_i^2}\right]\right] +$$
$$\frac{1}{\det A} * \left[\frac{\partial^2 U}{\partial C_i^2}\overline{e}\overline{k} \left[\frac{\partial^2 U}{\partial C_i^2}\overline{k}\overline{e} + \frac{\partial^2 U}{\partial g_i^2}\frac{\partial g_i}{\partial t_i}\frac{\partial g_i}{\partial \tau_i} + \frac{\partial U}{\partial g_i}\frac{\partial^2 g_i}{\partial t_i \partial \tau_i} + \frac{\partial^2 U}{\partial E_i^2}\frac{\partial E_i}{\partial t_i}\frac{\partial E_i}{\partial \tau_i} + \frac{\partial U}{\partial E_i}\frac{\partial^2 E_i}{\partial t_i \partial \tau_i}\right]\right]$$

$$\frac{dt_i}{dT_e} = \frac{1}{\det A} * \left[-\frac{\partial^2 U}{\partial C_i^2}\overline{e}\overline{k} \left[\frac{\partial^2 U}{\partial C_i^2}\overline{e}^2 + \frac{\partial^2 U}{\partial g_i^2}\left(\frac{\partial g_i}{\partial \tau_i}\right)^2 + \frac{\partial U}{\partial g_i}\frac{\partial^2 g_i}{\partial \tau_i^2} + \frac{\partial^2 U}{\partial E_i^2}\left(\frac{\partial E_i}{\partial \tau_i}\right)^2 + \frac{\partial U}{\partial E_i}\frac{\partial^2 E_i}{\partial \tau_i^2}\right]\right] +$$
$$\frac{1}{\det A} * \left[\frac{\partial^2 U}{\partial C_i^2}\overline{e}^2 \left[\frac{\partial^2 U}{\partial C_i^2}\overline{k}\overline{e} + \frac{\partial^2 U}{\partial g_i^2}\frac{\partial g_i}{\partial t_i}\frac{\partial g_i}{\partial \tau_i} + \frac{\partial U}{\partial g_i}\frac{\partial^2 g_i}{\partial t_i \partial \tau_i} + \frac{\partial^2 U}{\partial E_i^2}\frac{\partial E_i}{\partial t_i}\frac{\partial E_i}{\partial \tau_i} + \frac{\partial U}{\partial E_i}\frac{\partial^2 E_i}{\partial t_i \partial \tau_i}\right]\right]$$

$$\frac{d\tau_i}{dT_k} = \frac{1}{\det A} * \left[-\frac{\partial^2 U}{\partial C_i^2}\overline{e}\overline{k} \left[\frac{\partial^2 U}{\partial C_i^2}\overline{k}^2 + \frac{\partial^2 U}{\partial g_i^2}\left(\frac{\partial g_i}{\partial t_i}\right)^2 + \frac{\partial U}{\partial g_i}\frac{\partial^2 g_i}{\partial t_i^2} + \frac{\partial^2 U}{\partial E_i^2}\left(\frac{\partial E_i}{\partial t_i}\right)^2 + \frac{\partial U}{\partial E_i}\frac{\partial^2 E_i}{\partial t_i^2}\right]\right] +$$
$$\frac{1}{\det A} * \left[\frac{\partial^2 U}{\partial C_i^2}\overline{k}^2 \left[\frac{\partial^2 U}{\partial C_i^2}\overline{e}\overline{k} + \frac{\partial^2 U}{\partial g_i^2}\frac{\partial g_i}{\partial \tau_i}\frac{\partial g_i}{\partial t_i} + \frac{\partial U}{\partial g_i}\frac{\partial^2 g_i}{\partial \tau_i \partial t_i} + \frac{\partial^2 U}{\partial E_i^2}\frac{\partial E_i}{\partial \tau_i}\frac{\partial E_i}{\partial t_i} + \frac{\partial U}{\partial E_i}\frac{\partial^2 E_i}{\partial \tau_i \partial t_i}\right]\right]$$

$$\frac{d\tau_i}{dT_e} = \frac{1}{\det A} * \left[-\frac{\partial^2 U}{\partial C_i^2}\overline{e}^2 \left[\frac{\partial^2 U}{\partial C_i^2}\overline{k}^2 + \frac{\partial^2 U}{\partial g_i^2}\left(\frac{\partial g_i}{\partial t_i}\right)^2 + \frac{\partial U}{\partial g_i}\frac{\partial^2 g_i}{\partial t_i^2} + \frac{\partial^2 U}{\partial E_i^2}\left(\frac{\partial E_i}{\partial t_i}\right)^2 + \frac{\partial U}{\partial E_i}\frac{\partial^2 E_i}{\partial t_i^2}\right]\right] +$$
$$\frac{1}{\det A} * \left[+\frac{\partial^2 U}{\partial C_i^2}\overline{k}\overline{e} \left[\frac{\partial^2 U}{\partial C_i^2}\overline{e}\overline{k} + \frac{\partial^2 U}{\partial g_i^2}\frac{\partial g_i}{\partial \tau_i}\frac{\partial g_i}{\partial t_i} + \frac{\partial U}{\partial g_i}\frac{\partial^2 g_i}{\partial \tau_i \partial t_i} + \frac{\partial^2 U}{\partial E_i^2}\frac{\partial E_i}{\partial \tau_i}\frac{\partial E_i}{\partial t_i} + \frac{\partial U}{\partial E_i}\frac{\partial^2 E_i}{\partial \tau_i \partial t_i}\right]\right]$$

with

$$\det A \equiv \left[\frac{\partial^2 U}{\partial C_i^2}\overline{k}^2 + \frac{\partial^2 U}{\partial g_i^2}\left(\frac{\partial g_i}{\partial t_i}\right)^2 + \frac{\partial U}{\partial g_i}\frac{\partial^2 g_i}{\partial t_i^2} + \frac{\partial^2 U}{\partial E_i^2}\left(\frac{\partial E_i}{\partial t_i}\right)^2 + \frac{\partial U}{\partial E_i}\frac{\partial^2 E_i}{\partial t_i^2}\right] *$$
$$\left[\frac{\partial^2 U}{\partial C_i^2}\overline{e}^2 + \frac{\partial^2 U}{\partial g_i^2}\left(\frac{\partial g_i}{\partial \tau_i}\right)^2 + \frac{\partial U}{\partial g_i}\frac{\partial^2 g_i}{\partial \tau_i^2} + \frac{\partial^2 U}{\partial E_i^2}\left(\frac{\partial E_i}{\partial \tau_i}\right)^2 + \frac{\partial U}{\partial E_i}\frac{\partial^2 E_i}{\partial \tau_i^2}\right] -$$
$$\left[\frac{\partial^2 U}{\partial C_i^2}\overline{e}\overline{k} + \frac{\partial^2 U}{\partial g_i^2}\frac{\partial g_i}{\partial \tau_i}\frac{\partial g_i}{\partial t_i} + \frac{\partial U}{\partial g_i}\frac{\partial^2 g_i}{\partial \tau_i \partial t_i} + \frac{\partial^2 U}{\partial E_i^2}\frac{\partial E_i}{\partial \tau_i}\frac{\partial E_i}{\partial t_i} + \frac{\partial U}{\partial E_i}\frac{\partial^2 E_i}{\partial \tau_i \partial t_i}dt_i\right] *$$
$$\left[\frac{\partial^2 U}{\partial C_i^2}\overline{k}\overline{e} + \frac{\partial^2 U}{\partial g_i^2}\frac{\partial g_i}{\partial t_i}\frac{\partial g_i}{\partial \tau_i} + \frac{\partial U}{\partial g_i}\frac{\partial^2 g_i}{\partial t_i \partial \tau_i} + \frac{\partial^2 U}{\partial E_i^2}\frac{\partial E_i}{\partial t_i}\frac{\partial E_i}{\partial \tau_i} + \frac{\partial U}{\partial E_i}\frac{\partial^2 E_i}{\partial t_i \partial \tau_i}\right]$$

The impact of federal taxes only go through private consumption. Federal taxes alter neither the regional public good provision nor the environmental quality. If we assumed $\frac{\partial^2 U}{\partial C_i^2} = 0$, i.e. a quasi-linear utility function, which is quite standard in the tax competition literature, we would have $\frac{dt_i}{dT_k} = \frac{dt_i}{dT_e} = \frac{d\tau_i}{dT_k} = \frac{d\tau_i}{dT_e} = 0$, therefore implying that federal taxes have no impact on regional taxation.

We finally determine how each regional government chooses its capital tax rate w.r.t. its energy tax rate:

$$\frac{dt_i}{d\tau_i} = -[\frac{\partial^2 U}{\partial C_i^2}\overline{e}\left(\overline{k}-\overline{e}\right) + \frac{\partial^2 U}{\partial g_i^2}\frac{\partial g_i}{\partial \tau_i}\left(\frac{\partial g_i}{\partial t_i} - \frac{\partial g_i}{\partial \tau_i}\right) + \frac{\partial U}{\partial g_i}\left(\frac{\partial^2 g_i}{\partial t_i \partial \tau_i} - \frac{\partial^2 g_i}{\partial \tau_i^2}\right) + \frac{\partial^2 U}{\partial E_i^2}\frac{\partial E_i}{\partial \tau_i}\left(\frac{\partial E_i}{\partial t_i} - \frac{\partial E_i}{\partial \tau_i}\right) + \frac{\partial U}{\partial E_i}\left(\frac{\partial^2 E_i}{\partial t_i \partial \tau_i} - \frac{\partial^2 E_i}{\partial \tau_i^2}\right)]/ [\frac{\partial^2 U}{\partial C_i^2}\overline{k}\left(\overline{k}-\overline{e}\right) + \frac{\partial^2 U}{\partial g_i^2}\frac{\partial g_i}{\partial t_i}\left(\frac{\partial g_i}{\partial t_i} - \frac{\partial g_i}{\partial \tau_i}\right) + \frac{\partial U}{\partial g_i}\left(\frac{\partial^2 g_i}{\partial t_i^2} - \frac{\partial^2 g_i}{\partial \tau_i \partial t_i}\right) + \frac{\partial^2 U}{\partial E_i^2}\frac{\partial E_i}{\partial t_i}\left(\frac{\partial E_i}{\partial t_i} - \frac{\partial E_i}{\partial \tau_i}\right) + \frac{\partial U}{\partial E_i}\left(\frac{\partial^2 E_i}{\partial t_i^2} - \frac{\partial^2 E_i}{\partial \tau_i \partial t_i}\right)]$$

The trade-off between the two regional taxes depends on the relative size of the endowments $\overline{k}$ and $\overline{e}$, and on the comparison between the distortive effects of these taxes on both the regional public good and the environmental quality, as well as on the interdependence between the two taxes.

2.5 Conclusion

This chapter analyzes the tax interactions among two-tier governments, composed of several regional governments and a federal government, which both share two tax bases, that are capital and energy. The particularity of the energy is that it influences the quality of environment. But as capital and energy are two interdependent production factors, the taxation of capital also indirectly affects the quality of environment. We find that the federal trade-off between the taxation of capital versus the taxation of energy only depends on the relative exogenous supply of energy and capital. The regional trade-off between the taxation of capital versus the taxation of energy is much more complex as it also depends on the comparison between the distortive effects of these taxes on both the regional public good and the environmental quality, as well as on the interdependence between the two taxes. We also find a substitutability among federal and regional taxes, whatever the interdependence between the two taxes, implying that the federal government increases a given tax rate in response to a decrease of one of the two regional tax rates.

Several extensions can be considered to improve our understanding of the architecture of energy fiscal federalism. Firstly, we can make some ad-hoc assumptions to simplify our results instead of general functional forms of the utility function and the production function. We also plan to do a numerical investigation of optimal energy tax policies. Finally, the symmetry assumption could also be relaxed by considering that jurisdictions differ in terms of population.

2.6 Appendices

2.6.1 Appendix B1: Profit maximization and market clearing conditions

Profit maximization

Differentiating with respect to k_i and energy e_i the first-order conditions of profit maximization

$$\begin{cases} f_{k_i} = r_i^k \\ f_{e_i} = r_i^e \end{cases}$$

, which represent the implicit demands for respectively, capital and energy inputs, gives:

$$\begin{cases} f_{kk} dk_i + f_{ke} de_i = dr_i^k \\ f_{ek} dk_i + f_{ee} de_i = dr_i^e \end{cases}$$

Using Cramer's rule gives:

$$dk_i = \frac{f_{ee} dr_i^k - f_{ke} dr_i^e}{f_{kk} f_{ee} - f_{ek} f_{ke}} \tag{2.7}$$

$$de_i = \frac{f_{kk} dr_i^e - f_{ek} dr_i^k}{f_{kk} f_{ee} - f_{ek} f_{ke}} \tag{2.8}$$

Since production factors are perfectly mobile, $\rho_{k_i} = \rho_k$, $\rho_{e_i} = \rho_e$ $\forall i$.

The demand functions of capital and energy depend on all remunerations of production factors $(\rho_k, \rho_e, t_j, \tau_j)$ $\forall j$.

Assuming that $f_{ek} = f_{ke}$, we derive that:

$$k_{r^k} = \frac{dk_i}{dr_i^k} = \frac{f_{ee}}{f_{kk} f_{ee} - f_{ek} f_{ke}} \tag{2.9}$$

$$e_{r^e} = \frac{de_i}{dr_i^e} = \frac{f_{kk}}{f_{kk} f_{ee} - f_{ek} f_{ke}} \tag{2.10}$$

$$k_{r^e} \equiv \frac{dk_i}{dr_i^e} = \frac{-f_{ke}}{f_{kk}f_{ee} - f_{ek}f_{ke}} = e_{r^k} \equiv \frac{de_i}{dr_i^k} = \frac{-f_{ek}}{f_{kk}f_{ee} - f_{ek}f_{ke}} \tag{2.11}$$

Market clearing conditions

Differentiating with respect to ρ_k, ρ_e, t_i, τ_i, T_k and T_e the following market-clearing conditions

$$\sum_{i=1}^{n} k(\rho_k + t_i + T_k, \rho_e + \tau_i + T_e) = n\bar{k} \tag{2.12}$$

$$\sum_{i=1}^{n} e(\rho_k + t_i + T_k, \rho_e + \tau_i + T_e) = n\bar{e} \tag{2.13}$$

yields, at the symmetric equilibrium:

$$\sum_{i=1}^{n} k_{r_i^k} d\rho_k + \sum_{i=1}^{n} k_{r_i^e} d\rho_e + k_{r_i^k} dt_i + k_{r_i^e} d\tau_i + \sum_{i=1}^{n} k_{r_i^k} dT_k + \sum_{i=1}^{n} k_{r_i^e} dT_e = 0 \tag{2.14}$$

$$\sum_{i=1}^{n} e_{r_i^k} d\rho_k + \sum_{i=1}^{n} e_{r_i^e} d\rho_e + e_{r_i^k} dt_i + e_{r_i^e} d\tau_i + \sum_{i=1}^{n} e_{r_i^k} dT_k + \sum_{i=1}^{n} e_{r_i^e} dT_e = 0 \tag{2.15}$$

By dividing the system formed by equations (2.14) and (2.15) by dt_i, we obtain at symmetric equilibrium:

$$\begin{cases} \sum_{i=1}^{n} k_{r_i^k} \frac{d\rho_k}{dt_i} + \sum_{i=1}^{n} k_{r_i^e} \frac{d\rho_e}{dt_i} = -k_{r_i^k} \\ \sum_{i=1}^{n} e_{r_i^k} \frac{d\rho_k}{dt_i} + \sum_{i=1}^{n} e_{r_i^e} \frac{d\rho_e}{dt_i} = -e_{r_i^k} \end{cases}$$

which gives:

$$\frac{d\rho_k}{dt_i} = \frac{e_{r_i^k} \sum k_{r_i^e} - k_{r_i^k} \sum e_{r_i^e}}{\sum k_{r_i^k} \sum e_{r_i^e} - \sum k_{r_i^e} \sum e_{r_i^k}} = \frac{n(f_{ek}f_{ke} - f_{kk}f_{ee})}{n^2(f_{kk}f_{ee} - f_{ke}f_{ek})} = \frac{-1}{n} \tag{2.16}$$

$$\frac{d\rho_e}{dt_i} = \frac{k_{r_i^k} \sum e_{r_i^k} - e_{r_i^k} \sum k_{r_i^k}}{\sum k_{r_i^k} \sum e_{r_i^e} - \sum k_{r_i^e} \sum e_{r_i^k}} = \frac{-nf_{ee}f_{ek} - (-nf_{ee}f_{ek})}{n^2(f_{kk}f_{ee} - f_{ke}f_{ek})} = 0 \tag{2.17}$$

By dividing the system formed by equations (2.14) and (2.15) by $d\tau_i$, we obtain at symmetric equilibrium:

$$\begin{cases} \sum_{i=1}^{n} k_{r_i^k} \frac{d\rho_k}{d\tau_i} + \sum_{i=1}^{n} k_{r_i^e} \frac{d\rho_e}{d\tau_i} = -k_{r_i^e} \\ \sum_{i=1}^{n} e_{r_i^k} \frac{d\rho_k}{d\tau_i} + \sum_{i=1}^{n} e_{r_i^e} \frac{d\rho_e}{d\tau_i} = -e_{r_i^e} \end{cases}$$

which gives:

$$\frac{d\rho_k}{d\tau_i} = \frac{e_{r_i^e} \sum k_{r_i^e} - k_{r_i^e} \sum e_{r_i^e}}{\sum k_{r_i^k} \sum e_{r_i^e} - \sum k_{r_i^e} \sum e_{r_i^k}} = \frac{-n f_{kk} f_{ke} - (-n f_{ke} f_{kk})}{n^2 (f_{kk} f_{ee} - f_{ke} f_{ek})} = 0 \tag{2.18}$$

$$\frac{d\rho_e}{d\tau_i} = \frac{k_{r_i^e} \sum e_{r_i^k} - e_{r_i^e} \sum k_{r_i^k}}{\sum k_{r_i^k} \sum e_{r_i^e} - \sum k_{r_i^e} \sum e_{r_i^k}} = \frac{-n f_{ke} f_{ek} - (-n f_{kk} f_{ee})}{n^2 (f_{kk} f_{ee} - f_{ke} f_{ek})} = \frac{-1}{n} \tag{2.19}$$

In the same way, we obtain:

$$\frac{d\rho_k}{dT_k} = \frac{\sum_{i=1}^{n} k_{r_i^e} \sum e_{r_i^k} - \sum_{i=1}^{n} k_{r_i^k} \sum e_{r_i^e}}{\sum k_{r_i^k} \sum e_{r_i^e} - \sum k_{r_i^e} \sum e_{r_i^k}} = \frac{-n f_{ke}(-n f_{ek}) - (-n f_{kk} n f_{ee})}{n^2 (f_{kk} f_{ee} - f_{ke} f_{ek})} = -1 \tag{2.20}$$

$$\frac{d\rho_e}{dT_k} = \frac{\sum_{i=1}^{n} k_{r_i^k} \sum e_{r_i^k} - \sum_{i=1}^{n} k_{r_i^k} \sum e_{r_i^k}}{\sum k_{r_i^k} \sum e_{r_i^e} - \sum k_{r_i^e} \sum e_{r_i^k}} = 0 \tag{2.21}$$

$$\frac{d\rho_k}{dT_e} = \frac{\sum_{i=1}^{n} k_{r_i^e} \sum e_{r_i^e} - \sum_{i=1}^{n} k_{r_i^e} \sum e_{r_i^e}}{\sum k_{r_i^k} \sum e_{r_i^e} - \sum k_{r_i^e} \sum e_{r_i^k}} = 0 \tag{2.22}$$

$$\frac{d\rho_e}{dT_e} = \frac{\sum_{i=1}^{n} k_{r_i^e} \sum e_{r_i^k} - \sum_{i=1}^{n} k_{r_i^k} \sum e_{r_i^e}}{\sum k_{r_i^k} \sum e_{r_i^e} - \sum k_{r_i^e} \sum e_{r_i^k}} = -1 \tag{2.23}$$

2.6.2 Appendix B2: Intermediate details of maximization program derived at the symmetric equilibrium

Appendix B1: Impact of taxes on private consumption

$$\pi_i = f(k_i, e_i) - r_i^k k_i - r_i^e e_i \tag{2.24}$$

$\frac{d\pi_i}{dr_i^k} = \pi'_{r_i^k} = f'_k.\frac{dk_i}{dr_i^k} + f'_e.\frac{de_i}{dr_i^k} - k_i - r_i^k \frac{dk_i}{dr_i^k} - r_i^e \frac{de_i}{dr_i^k}$

$\pi'_{r_i^k} = (f'_k - r_i^k)\frac{dk_i}{dr_i^k} + (f'_e - r_i^e)\frac{de_i}{dr_i^k} - k_i$

$\pi'_{r_i^k} = -k_i.$

$\pi'_{r_i^e} = (f'_k - r_i^k)\frac{dk_i}{dr_i^e} + (f'_e - r_i^e)\frac{de_i}{dr_i^e} - e_i$

$\pi'_{r_i^e} = -e_i$.

$$C_i = \pi_i + \rho_{k_i}\overline{k} + \rho_{e_i}\overline{e} \tag{2.25}$$

$\frac{dC_i}{dt_i} = \pi'_{r_i^k}\frac{dr_i^k}{dt_i} + \overline{k}\frac{d\rho_k}{dt_i}$

$\frac{dC_i}{dt_i} = -k_i(1 + \frac{d\rho_k}{dt_i}) + \overline{k}\frac{d\rho_k}{dt_i}$

$$\frac{dC_i}{dt_i} = -\overline{k} \tag{2.26}$$

$\frac{dC_i}{d\tau_i} = \pi'_{r_i^e}\frac{dr_i^e}{d\tau_i} + \overline{e}\frac{d\rho_e}{d\tau_i}$

$\frac{dC_i}{d\tau_i} = -e_i(1 + \frac{d\rho_e}{d\tau_i}) + \overline{e}\frac{d\rho_e}{d\tau_i}$

$$\frac{dC_i}{d\tau_i} = -\overline{e} \tag{2.27}$$

$\frac{dC_i}{dT_k} = \overline{k}\frac{d\rho_k}{dT_k}$

$$\frac{dC_i}{dT_k} = -\overline{k} \tag{2.28}$$

$$\frac{dC_i}{dT_e} = -\overline{e} \tag{2.29}$$

2.6.3 Appendix B3: Impact of taxes on regional public good

$$g_i = t_i k_i + \tau_i e_i \tag{2.30}$$

$\frac{dg_i}{dt_i} = k_i + t_i \frac{dk_i}{dr_i^k}\frac{dr_i^k}{dt_i} + \tau_i \frac{de_i}{dr_i^k}\frac{dr_i^k}{dt_i} = k_i + (t_i.k_{r_i^k} + \tau_i.e_{r_i^k})\frac{dr_i^k}{dt_i}$

$$\frac{dg_i}{dt_i} = k_i + \frac{n-1}{n} * \frac{1}{f_{kk}f_{ee} - f_{ke}f_{ek}}(t_i f_{ee} - \tau_i f_{ek}) \tag{2.31}$$

$\frac{dg_i}{d\tau_i} = e_i + t_i \frac{dk_i}{dr_i^e}\frac{dr_i^e}{d\tau_i} + \tau_i \frac{de_i}{dr_i^e}\frac{dr_i^e}{d\tau_i} = e_i + (t_i.k_{r_i^e} + \tau_i.e_{r_i^e})\frac{dr_i^e}{d\tau_i}$

$$\frac{dg_i}{d\tau_i} = e_i + \frac{n-1}{n} * \frac{1}{f_{kk}f_{ee} - f_{ke}f_{ek}}(-t_i f_{ke} + \tau_i f_{kk}) \tag{2.32}$$

$$\frac{dg_i}{dT_k} = \frac{dg_i}{dT_e} = 0 \tag{2.33}$$

2.6.4 Appendix B4: Impact of taxes on federal public good

$$G = \frac{1}{n}T_k \sum k(r_i^k, r_i^e) + \frac{1}{n}T_e \sum e(r_i^k, r_i^e) \tag{2.34}$$

$\frac{dG}{dt_i} = \frac{1}{n}T_k(k_{r_i^k}\frac{dr_i^k}{dt_i} + \sum_{j\neq i} k_{r_j^k}\frac{dr_j^k}{dt_i}) + \frac{1}{n}T_e(e_{r_i^k}\frac{dr_i^k}{dt_i} + \sum_{j\neq i} e_{r_j^k}\frac{dr_j^k}{dt_i})$

$\frac{dG}{dt_i} = \frac{1}{n}T_k(\frac{f_{ee}}{f_{kk}f_{ee}-f_{ek}f_{ke}})[\frac{n-1}{n} + (n-1)(\frac{-1}{n})] - \frac{1}{n}T_e(\frac{f_{ek}}{f_{kk}f_{ee}-f_{ek}f_{ke}})[\frac{n-1}{n} + (n-1)(\frac{-1}{n})]$

$$\frac{dG}{dt_i} = 0 \tag{2.35}$$

$\frac{dG}{d\tau_i} = \frac{1}{n}T_k(k_{r_i^e}\frac{dr_i^e}{d\tau_i} + \sum_{j\neq i} k_{r_j^e}\frac{dr_j^e}{d\tau_i}) + \frac{1}{n}T_e(e_{r_i^e}\frac{dr_i^e}{d\tau_i} + \sum_{j\neq i} e_{r_j^e}\frac{dr_j^e}{d\tau_i})$

$\frac{dG}{d\tau_i} = \frac{1}{n}T_k(\frac{-f_{ek}}{f_{kk}f_{ee}-f_{ek}f_{ke}})[\frac{n-1}{n} + (n-1)(\frac{-1}{n})] + \frac{1}{n}T_e(\frac{f_{kk}}{f_{kk}f_{ee}-f_{ek}f_{ke}})[\frac{n-1}{n} + (n-1)(\frac{-1}{n})]$

$$\frac{dG}{d\tau_i} = 0 \tag{2.36}$$

$$\frac{dG}{dT_k} = \frac{1}{n}\sum k(r_i^k, r_i^e) = k_i \tag{2.37}$$

and

$$\frac{dG}{dT_e} = \frac{1}{n}\sum e(r_i^k, r_i^e) = e_i \tag{2.38}$$

2.6.5 Appendix B5: Impact of taxes on environment

$E_i = h(e_i)$

$\frac{dE_i}{dt_i} = \frac{dh}{de_i}\frac{de_i}{dr_i^k}\frac{dr_i^k}{dt_i} = E_e.e_{r_i^k}\frac{n-1}{n}$

$$\frac{dE_i}{dt_i} = -E_e\frac{n-1}{n}\frac{f_{ek}}{f_{kk}f_{ee} - f_{ke}f_{ek}} \tag{2.39}$$

$\frac{dE_i}{d\tau_i} = E_e.e_{r_i^e}\frac{dr_i^e}{d\tau_i}$

$$\frac{dE_i}{d\tau_i} = E_e\frac{n-1}{n}\frac{f_{kk}}{f_{kk}f_{ee} - f_{ke}f_{ek}} \tag{2.40}$$

$$\frac{dE_i}{dT_k} = \frac{dE_i}{dT_e} = 0 \tag{2.41}$$

Chapter 3

Environmental expenditure interactions among countries:

A spatial panel data analysis of OECD countries case over the period 1994-2014.

Abstract

In this paper, we test whether there is spatial interdependence among OECD countries for environmental expenditures. For that purpose, we use a panel dataset of 30 OECD countries over the 1994–2014 period and include a large range of economic and political control variables. We find positive spatial interdependence in environmental expenditures. We also observe that political characteristics affect the size of environmental expenditures: the higher are civil liberties (resp. political rights), the higher are environmental expenditures (resp. lower are environmental expenditures). We also find that the percentage of eldery impacts negatively public environmental expenditures. Additionally, we test spatial interactions on R&D budget in energy and in CO2 emissions and for both issues, we find evidence of positive spatial interaction effects. Results are robust to the concept of neighborhood.

3.1 Introduction

Environmental challenges are increasing the pressure on governments to find ways to reduce environmental damages. In order to alleviate these damages, governments have a range of tools at their disposal, including regulations, information programmes, innovation policies, environmental taxes, subsidies and environmental expenditure. Expenditures in particular are a key part of this toolkit. They aim at dealing with market failures linked to environment-related externalities. According to Pearce and Palmer (2001), despite being largely neglected, expenditure for environmental protection is crucial for improving social welfare. Nevertheless, it is still low with respect to both its nominal value and its share in Gross Domestic Product (GDP). Indeed, in 2016, the EU28 average general government expenditure for environmental protection amounted to 0.7% of GDP (Source:

Eurostat[21]).

Since the last decades, research on strategic interactions have seen a huge increase with regard to public service provision. However, interactions in specific environmental issues have hitherto received scant attention although environmental degradation obvioulsy overcomes national boundaries. Therefore, common transnational efforts should be required to cope with it. The Sustainable Development Goals and the Paris Agreement represent global commitment are steps towards tackling the negative effects of climate change on the natural environment. In Europe, sectorial directives and strategies such as Europe 20 20 20 contribute to align environmental policies and stimulate efforts towards greater water quality, less waste production and energy savings, amongst others Ercolano and Romano (2017). More specifically, in terms of public policy, with European citizens becoming increasingly aware of environmental problems, the European Union adopted a series of Directives, strategies and programmes (Waste Framework Directive, Water Framework Directive, EU Biodiversity Strategy to 2020, Clean Air Policy Package, etc.) designed to move Europe towards a sustainable growth based in particular on environmental protection activities [22].

There exists a large literature justifying spatial dependence in public choice: these include tax competition (Wilson (1999) for a survey); spillover benefits (Wilson (1996)); welfare competition (Brueckner (2000)) and yardstick competition (Besley and Case (1995)). With respect to public spending policies, the seminal papers are those of Case et al. (1993) and Kelejian and Robinson (1993) that have led stimulated various approaches that explored the relations between local public spending policies and their spatial spillover effects. Regarding spending policies literature, there are mainly three reasons through which spending behaviors of a country can be affected by those neighboring countries. Firstly, if a country compete with its neighbors to attract households or firms (Case et al. (1993); Revelli (2003); Lundberg (2006)), there is expenditure competition. Secondly, there is yardstick competition if countries' spending promotes development and growth to ensure reelection ((Chen et al. (2005); Caldeira (2012)). Finally, if public spending can create benefits (or have detrimental effects) on its neighboring countries, expenditure externalities occur (Ollé (2003); Freret et al. (2005)). In the same perspective, López et al. (2017) show that both revenue and expenditure policies display spatial spillovers because of the impact of decisions made by authorities in neighbouring regions[23]. These spending policies and their spatial spillovers have generated special interest for investigators. Strategic interaction on environmental policy is the interplay on setting policies across different governments, which is measured by the degree of change in one jurisdiction's environmental policy in reaction to the weighted average of other jurisdictions' changes in environmental policies (Tang et al. (2017)).

[21]Eurostat:Environmental protection expenditure accounts handbook, edition 2017.

[22]Government expenditure on environmental protection (http://ec.europa.eu/eurostat/statistics-explained/index.php)

[23]For example, a low-tax policy in neighbouring regions can be attractive to both citizens and business, and therefore, the region should have similar tax levels if they do not want citizens to move to neighboring regions. The same philosophy can be transferred to expenditure in public services, particularly with subprogrammes that are intrinsically linked to citizen welfare.

Focusing explicitly on interactions in public expenditure, some studies analyze spatial spillovers in spending policies for various fields such as local governments (Case et al. (1993); Solé-Ollé (2006)), cultural items (Lundberg (2006); Werck et al. (2008); Šť'astná (2009); Benito et al. (2013)), sport and recreational activities (Šť'astná (2009); Ermini and Santolini (2010)) or environment (Šť'astná (2009); Ermini and Santolini (2010); Deng et al. (2012); Choumert and Cormier (2011)). For instance, using a cross-sectional dataset including 249 Chinese cities in 2005, Deng et al. (2012) examine the factors that determine public environmental protection spending in a decentralized economy. Their results reveal that city governments do behave strategically in making spending decisions relating to environmental protection. In other words, a city government tends to cut its own spending as a response to a rise in the environmental protection spending of its neighbors. However, most of the papers that study strategic interactions use state level data within one country; the number of papers that conduct cross-country analysis is small.

Uncovering possible existence of environmental expenditures interactions between countries is interesting for various reasons. Firstly, it allows to compare efforts that countries make for environmental protection. Indeed, in the context of the challenge with climate change, countries play a major role in environmental protection, through setting environmental regulations and environmental protection expenditure. Hence, countries can be tempted to adopt a mimicking behavior when they spend in favor of environmental protection in order to promote their self. Secondly, as mentioned above, due to the potential existence of expenditure externalities, countries' policy choices are not independent. In terms of environmental expenditures, these externalities could be the amount of public investments in environmental infrastructures in a country whose benefits spill over in neighboring countries, and therefore affect the level of investments in the latter countries. Another type of interdependency regarding environmental expenditure policy is based on the idea that citizens can evaluate the performances of their policy makers by comparing the same policy choices taken by the neighboring countries. In the same vein, environmental expenditure policies can affect business location decisions. For example, countries that impose higher environmental standards (in terms of investments for environmental protection) can encourage businesses to relocate to countries with lower environmental standards.

Apart from the rare papers analzing spatial interaction in environmental expenditures, to the best of our knowledge no contribution has investigated the potential environmental expenditures interactions among countries so far. This study fills this gap by combining work on spatial and strategic interaction in public choices, to test whether there are strategic interactions in decisions related to the amount of OECD countries expenditure. Using a panel dataset of 30 OECD countries over the period 1994-2014, the paper applies spatial econometric methods to examine the existence of spatial public environmental expenditure, using a wide range of economic and political control variables. Our estimation strategy is based on an instrumental variables (IV) approach (Kelejian and Robinson (1993); Kelejian and Prucha (1998)). The robustness of our regressions is evaluated with the usual tests after IV estimations. The empirical results reveal that countries do behave strategically in making spending decisions related to environmental expenditures. In other words, a country tends to cut its own spending as a response to a decrease in the environmental protection expenditure of its neighbors.

Furthermore, we also include two complementary analysis. On the one hand, as energy sector represents a large component of environmental expenditures, we carry out an complementary analysis on a specific field of environmental spending, namely R&D energy budget in order to see if our interaction results on environmental expenditures are generalizable or specific to particular expenditure items. The reasons underlying the interaction analysis of environmental expenditure (as described above) are also valid for the energy field. In addition, analysing this issue may provide invaluable information to policy makers across countries to help their decisions on energy RD&D investments. On the other hand, as environmental protection activities are shifting towards fighting climate change, reduction of air pollution and preservation of the biodiversity, it seemed appropriate to carry out a complementary analysis on CO2 emissions interaction in order to examine countries' behaviors in terms of air pollution. For both issues, we also find evidence of positive spatial interaction effects. Results are robust to the concept of neighborhood.

The remainder of this paper is structured as follows. The next section reviews the main contributions regarding the issue of spatial interactions in the environmental domain. Data used in the analysis are presented in Section 3, while the methodology adopted for data analysis is discussed in Section 4. Section 5 illustrates the results. Section 6 discusses how public expenditure for environmental protection is correlated with the environmental performance. Finally, conclusions are reported in Section 7.

3.2 Background literature

3.2.1 Strategic expenditure interactions

Spatial interactions among governments in public spending decisions have received considerable attention in the applied public economics literature. From a theoretical point of view, there are at least two mechanisms that can explain the potential strategic interactions in government expenditures. First, spatial interactions might be arising from the interdependence amongst governments due to expenditure competition that may be associated with the mimicking behavior or yardstick competion. The second and the foremost source is the presence of spillover effects in sense that the benefits of public spending in domestic regions can easily spill over to neighboring regions (Gordon (1983)).

From an empirical point of view, a huge literature highlights the evidence of spatial expenditure interactions (Case et al. (1993), Barreira (2011), Costa et al. (2015), Solé-Ollé (2006) among others). For instance, Case et al. (1993) test spatial expenditure interactions among states. They find that a state government's level of per capita expenditure is positively and significantly affected by the expenditure levels of its neighbors. In other words, a one dollar increase in a state's neighbors' expenditures increases its own expenditure by over 70 cents. Focusing on local governments in Portugal, Barreira (2011) seek to identify the underlying reasons for spatial interaction in public expenditures. They find evidence of the existence of spillovers effects. In the same perspective, Costa et al. (2015) analyse the degree of interaction between 278 Portuguese municipalities' expenditure levels by estimating a dynamic panel model, based on jurisdictional reaction functions, from 1986 to 2006. Their results reveal that local governments' spending decisions are significantly, and positively, influenced by the actions of neighbouring municipalities. In addition, in an attempt to identify the sources of interaction, they find that spatial interactions are due to spillovers that require coordination in expenditure items and to mimicking behaviour possibly to attract households and firms. Furthermore, Solé-Ollé (2006) identify and test two different types of expenditure spillovers: (i) "benefit spillovers," arising from the provision of local public goods, and (ii) "crowding spillovers," arising from the crowding of facilities by residents in neighboring jurisdictions. Using data on more than 2500 Spanish local governments for the year 1999, they show that both types of spillovers are relevant.

With respect to the literature on expenditure competition, Bartolini and Santolini (2012) and Redoano (2007) find that spatial expenditure interactions are related to yardstick competttition, while Foucault et al. (2008) and Zheng et al. (2015) underline the existence of mimicking behavior. For instance, Bartolini and Santolini (2012) investigate the presence of political yardstick competition on current spending decisions in a sample of Italian municipalities. Using a static spatial panel model, they find significant evidence of yardstick competition. At the level of European countries, Redoano (2007) investigate whether or not governments interact with their neighbors when they decide their fiscal policy. They find evidence of fiscal interdependencies consistently with the literature on tax and yardstick competition. Using a dataset for 31 Chinese provinces from 1998 to 2006, Zheng et al. (2015) provide a spatial Durbin panel analysis to test for fiscal interactions among China's provinces in their public spending on infrastructure. They find significant positive interactions across Chinese provincial governments. Further analysis attempting to distinguish between the possible sources of such fiscal interactions reveals evidence of expenditure competition instead of yardstick competition. Foucault et al. (2008) testing whether there exist spending interactions between French municipalities by estimating a dynamic panel data model. Their results suggest on the one hand that there are some interactions between neighbouring municipalities as regards primary and investment expenditures.

3.2.2 Focus on spatial environmental interactions

From a theoretical point of view, there is no consensus on the effect of decentralized environmental policy-making, whether it induces a "race to the bottom" or a "race to the top" (Levinson (1997)). Indeed, local governments may enact higher environmental standards to prevent undesirable facilities from locating within a jurisdiction, which would lead to a "race to the top". Furthermore, local governments could decide setting laxer environmental standards to attract and retain capital (occurrence of the race to the bottom, cf. Markusen et al. (1995); Wilson (1996); Esty and Geradin (1998)).

From an empirical point of view, there are only few studies focusing on spatial interactions in environmental expenditure. At the city-level, Deng et al. (2012) find that city governments behave strategically in making spending decisions regarding environmental protection. In other words, a city government appears to cut its own spending as a response to the rise in environmental protection spending by its neighbors. Hence, environmental protection tends to be underprovided.

They also suggest that centralizing the environmental protection responsibility to a higher level of government would be beneficial in terms of controlling pollution in China. Other studies underline the interdependency of environmental expenditure among countries, by determining whether countries use environmental regulation strategically to attract FDI. For instance, Ercolano and Romano (2017) investigate environmental expenditures interactions among European countries. Their results reveal that higher level of environmental performance seem to be positively correlated with the public expenditures in the environmental domain and partially with the different composition of the expenditure. In particular, countries seem to show greater similarities when the environmental expenditure is devoted either to waste management or to pollution abatement.

With respect to horizontal tax competition in setting environmental taxes, there is some empirical literature which highlights the presence of interdependence in states' environmental behavior. For instance, Konisky (2007) studies annual state-level enforcement of federal air, water, and hazardous waste pollution control regulation, covering the period from 1985 to 2000. He aims to test for the presence of interdependence in states' environmental regulatory behavior. He finds clear evidence of strategic interaction in state environmental regulatory behavior. Moreover, Levinson (2003) finds competition across states in the hazardous waste disposal tax rates. Additionally, Fredriksson and Millimet (2002) allow for strategic interactions across different policy variables. They find that considering strategic interactions in a single policy setting provides lower bound estimates. Davies and Naughton (2014) use spatial econometrics to estimate participation in 247 international environmental treaties by 139 countries over 20 years. They find evidence of strategic interaction in environmental policies. Evers et al. (2004) empirically explore whether tax competition in Europe is also important for a different tax, namely the excise on commercial diesel. They find evidence for the presence of tax competition in diesel excises in Europe. In other words, a 10% higher tax rate in neighboring countries (in terms of the user price) induces a country to raise its own rate by around 2 to 3%. This impact is robust for alternative specifications.

Furthermore, some papers find some evidence of the existence of a race to the top in the setting of environmental regulation. For instance, Holzinger and Sommerer (2011) analyze the development of 17 environmental regulations in 24 countries over a period of 35 years. They find a clear 'race to the top' of environmental regulation and provide indications of an active search for European environmental Harmonization.

While much of the literature has focused on base shifting and the resulting race-to-the-bottom" in tax rates, there is some evidence of negative fiscal externalities. The presence of negative fiscal externalities means that tax rates are likely to be strategic substitutes and that the optimal response to higher tax rates in other states is a low own-state tax rate. According to energy taxes, Marion and Muehlegger (2015) examine how tax compliance leads to fiscal externalities in the context of state diesel taxes in the U.S. Using annual, state-level data on taxed diesel quantities for 1983-2007, they find that local tax rates respond negatively to tax rates in other states, which is in contrast to the canonical race-to-the-bottom but is consistent with the sign of the estimated fiscal externalities. More precisely, a weighted average of other states' diesel tax rates is negatively correlated with own-state diesel tax revenue, suggesting that any base shifting is dominated by the effects of underreporting gallons consumed. In a context of air emissions, Xiaoguang Chen

(2015) examine the existence and the magnitude of spatial spillover effects of urban air pollution in Chinese cities. Their spatial econometric model is novel in the sense that their spatial weights matrix changes daily according to wind direction and wind speed, which is expected to increase the precision of their coefficient estimates. They find strong evidence of the existence of spatial spillover effects of urban air pollution in China.

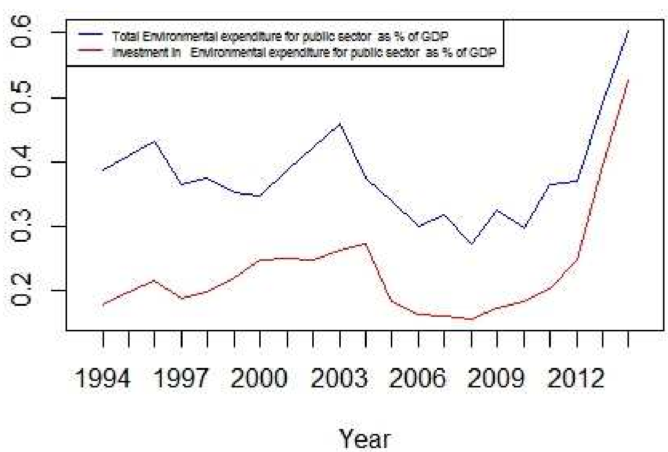
Despite the important influence that public spending may have on the environment, their relationship has not been studied extensively in the literature. However, in the past two years, evidence has begun to emerge regarding the empirical importance of their relationship. For instance, Halkos and Paizanos (2013) examine the impact of government spending on the environment using a panel of 77 countries for the time period 1980-2000. They estimate both the direct effect of government spending on pollution and the indirect effect which operates through government spending impact on per capita income and the subsequent effect of income level on pollution. Their results confirm the theoretical and empirical developments on the existence of a relationship between income and pollution as well between government size and economic performance. Indeed, they find that the direct effect of government expenditure is negative for both SO2 and CO2 per capita emissions and occurring with one year lag. Regarding waste management, Stafford (2000) examines how a commercial hazardous waste management firm's decision to locate a facility in a state is influenced by the characteristics of that state, including the stringency of state environmental standards. Their results indicate that state spending on environmental programs can deter firms, as does potential public opposition.

As mentioned above, to our knowledge, there are only a few papers (Deng et al. (2012) Ercolano and Romano (2017) Ermini and Santolini (2010)) that examine spatial interactions in environmental expenditures. In addition, most of these papers focus on the local fiscal policies with the exception of Ermini and Santolini (2010) who analyze spatial interactions among European countries. Therefore, the relevance of issues with regard to environmental public expenditures among OECD countries remains untested. This study tends to fill the gap using a new dataset that combines information on environmental spending varying over time (21 years) and across OECD countries. It contributes to the empirical literature on spatial interactions among jurisdictions and to the literature on the effectiveness of environmental policies. As previous empirical literature on environmental interactions emphasize on the mixed results using tax instruments, in this paper we focus on environmental spending in order to analyse the existence of spatial interactions among countries.

3.3 Data

To test for spatial interactions in environmental instruments, we use annual data on OECD countries compiled from different databases and reflecting economic, demographic, fiscal and environmental conditions. We consider several specifications of the model, where the dependent variable takes in turn environmental expenditure and budgetary levels of the public sector. On the expenditure side we use environmental protection expenditure as our dependent variable. This variable is the money spent on all purposeful activities directly aimed at the prevention, reduction and elimination of pollution or any other degradation of the environment. It includes environmental investments, environmental current expenditure and environmental subsidies/transfers. Environmental investments are all outlays in a given year for machinery, equipment and land used for environmental protection purposes. Current expenditure for environmental protection includes daily operating activities aiming at the prevention or reduction of pollution. It includes for example expenditure for staff working on environmental issues and materials for environmental protection[24]. Note that these data encompass different types of investment and current expenditure by several sectors and detailed by economic activity. However, taking into account the limitations that occur due to current data availability, in this study, we focus on public sector. Data collected at the country level are available starting from 1994 to 2014. As an illustration, figure 1 shows, respectively, the trend of the mean value for current expenditure and Investment for public sector between 1994 and 2014. This figure displays that after some ups and downs in the first few years, the situation improved in 2008-2014 for both current expenditure and investment.

Figure 3.1: Evolution of current expenditure and investment as % of GDP

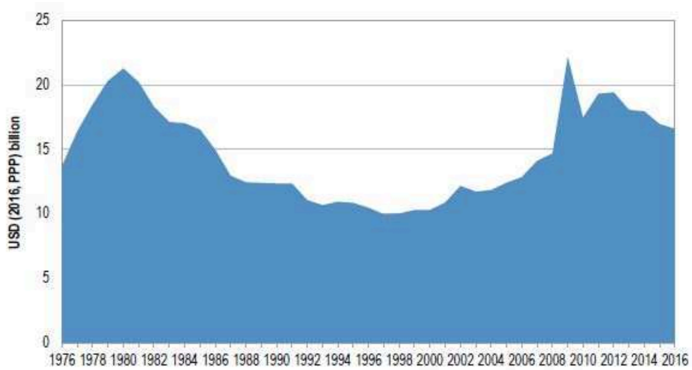


On the budgetary side, we explore International Energy Agency (IEA) data in order to test spatial interactions among OECD countries when planning energy RD&D budget. As collected

[24]It should be noted that environmental protection expenditure can be evaluated both according to the abater principle and the financing principle. This distinction makes it possible to aggregate different sectors and industries without double counting. On the one hand, expenditure according to the abater principle (EXP I), includes all expenditure that the sector has for measures they themselves execute. Any economic benefits directly linked with the environmental protection activities (Receipts from by-products) are deducted in order to calculate the net amount of money spent by the sector for their own activities. On the other hand, the financing principle (EXP II) measures how much money a particular sector (directly) contributes to overall environmental protection activities, wherever they are executed. This means that the part of EXP I that was directly financed by others (through subsidies or revenues received) should be deducted, while the part of EXP I in other sectors that this sector finances directly (through subsidies or fees paid) should be added.

by the IEA, these data provide invaluable information to policy makers across the globe to help their decisions on energy RD&D investments. These contain seven main branches of energy-related developments: (i) energy efficiency; (ii) fossil fuels (oil, gas and coal); (iii) renewables; (iv) nuclear fission and fusion; (v) hydrogen and fuel cells; (vi) other power and storage techniques; and (vii) other cross-cutting technologies or research. In this study, we analyze spatial interactions focusing on total energy RD&D budget across OECD countries. Figure 2 shows the evolution of total energy RD&D budget over time. In 2016, total energy RD&D budget reached close to USD 16.6 billion, just below 2015 levels. It continues to decrease year-on-year from its recent peak at USD 19.4 billion in 2012 (cf. figure 3.2). Despite this decline, total energy RD&D budget is maintained above the levels seen between 1985 and 2008. Futhermore, in order to access the impact of environmental policy on climate warning, we include CO2 emissions as our third dependent variable. This variable is obtained from the IEA's database of CO2 emissions from fuel combustion.

Figure 3.2: Evolution of total energy RD&D budget



Source: IEA Energy Technology RD&D Budgets (2017 edition)

We explicitly include two sets of control variables that may affect a countries' environmental instrument. Table 3.1 provides the definitions and sources for each variable. The first set of explanatory variables comprises economic resource variables, such as gross domestic product (GDP). It should be noted that there is a growing stream of works on the relationship between economic growth and environmental degradation. A common characteristic of these numerous case studies is the evidence of an inverse U-shaped of Environmental Kuznets Curve (thereafter EKC) between environmental degradation and income per capita Aldy (2005); Burnett et al. (2013); Carson (2009); Fosten et al. (2012); Grossman and Krueger (1995); Maddison (2006); Selden and Song (1994). EKC hypothesis means that as countries experience growth, CO2 emissions will increase at a decreasing rate with economic growth. For instance, Burnett et al. (2013) find a long-run relationship between the variables that suggests the inverted-U shaped relationship between CO2 emissions and personal income as espoused by the EKC.

The second dataset comprises 'expenditure needs' variables, such as the size of the population, the share of young population, the share of old the rate of unemployment and total energy consumption. For instance, a positive impact of population density on environmental expenditure denotes that potential congestion effects prevail over scale economies. Finally, we include political variables such as political rights (PR), civil liberties (CL); 1 represents the most free and 7 the least free rating.

Table 3.1: Descriptive statistics

Statistic	Definition	N	Mean	St. Dev.	Min	Max
tot_exp_pub_vf	Environmental expenditures of the public sector as % of GDP	568	0.38	0.35	0.00	3.27
rdd_nrj_total_budget	Total energy RDD in Million USD	768	27,907.72	107,934.60	0.36	837,727.00
tot_co2_emissions	Total CO2 emissions as % of GDP	630	160.57	190.66	1.86	887.15
Tot_final_cons	Total final consumption of energy	630	50,418.17	56,914.81	1,448.62	242,061.40
Population	Total population	1,189	33,328,346.00	52,523,060.00	355,050	318,563,456
Pct_pop_young	Percentage of young population	1,189	20.39	4.76	13.06	40.79
Pct_pop_active	Percentage of active population	1,189	66.11	2.50	54.84	72.23
Pct_pop_old	Percentage of old population	1,189	13.50	3.41	3.23	25.35
Unemployment	Unemployment rate	1,031	7.36	4.25	0.10	27.50
GDP_head	Gross Domestic Product per capita	567	27,233.48	20,072.41	2,221.22	115,761.50
PR	Political rights	1,610	1.66	1.39	1	7
CL	Civil liberties	1,610	1.88	1.34	1	7

3.4 Methodology

3.4.1 Econometric method

Using panel data for 30 OECD countries, an empirical model for environmental expenditures can be specified as follows:

$$E_{it} = \lambda \sum_{j=1}^{N} w_{ij} E_{jt} + x_{it}\beta + \mu_i + \varepsilon_{it} \tag{3.1}$$

where E_{it} is the environmental expenditure in country i and year t; w_{ij} corresponds to the spatial connectivity between country j and country i ($j \neq$ i) and is an element of W, an $N * N$ pre-specified spatial weights matrix with zeros on the diagonal; E_{jt} is the environmental expenditure in country j; β is a vector of the coefficients of the explanatory variables; X_{it} is a vector of characteristics of country i that explains its environmental expenditure and ε_{it} is a random error term typically assumed to be i.i.d.. In addition, there may be unobservable country shocks that are correlated with the environmental expenditure decisions. To address these concerns, we include country fixed effects μ_i which capture time invariant country-specific attributes such as natural endowment. The omission of these specific characteristics might bias the estimates in a panel data analysis (Baltagi (2008); Elhorst (2010)).

The spatial scalar parameter, λ, reflects the endogenous spatial interaction between country i and its neighboring countries. In other words, it shows the presence of an attribute in country i makes its presence in neighboring countries more or less likely (Choumert and Cormier (2011)). When $\lambda = 0$, it suggests that there is no endogenous spatial interaction. Hence, the environmental expenditure provision is irrelevant to the spatial connectivity amongst countries. If $\lambda \neq 0$, two possibilities arise. On the one hand, if $\lambda > 0$, i.e., the environmental expenditure provision in neighboring countries tends to be more similar than the environmental expenditure provided in remote countries, and therefore the neighboring countries follow a mimicking strategy. On the other hand, if $\lambda < 0$ would suggest that the environmental expenditure provision in nearby countries tends to be more diverse and demonstrates dissimilarity. In this perspective, countries follow a substituting strategy and involve possible of free-riding behaviors between countries. More generally, a negative value of λ implies the presence of an expenditure externality, while a positive value of λ implies possible coexistence of an expenditure externality, yardstick competition and expenditure competition Brueckner (2003). The spatial econometric models are estimated by a feasible instrumental variables method with robust standard error Baum et al. (2003). Details on the set of instruments used are provided in the following sub-section.

3.4.2 Weighting matrices

The spatial specification implies the definition of a neighbouring relationship which is represented by a matrix that defines the connectivity structure among countries through a weighting attribution. In this regard, I construct 2 separate weighting matrices. Each is used to create a composite "neighbor" for each of the OECD countries and composite values for that neighbor's environmental expenditure, covariates, and instruments. First, following the empirical literature, we choose a geographical definition of neighborhood based on k nearest neighbors (in this study, $k = 3$). Second, to check robustness, I also consider an alternative weight matrix which is the inverse distance matrix ($1/d_{ij}$), where d_{ij} is the (greater-circle) distance between country i and country j (calculated based on the longitude and latitude of each city). This matrix takes into account relations of all countries, which allows for testing all-with-all interactions in the whole sample.

3.4.3 Instrumental variables method

The econometric estimation of Eq. 3.4.1 presents a number of challenges. Firstly, the neighboring countries' environmental expenditure are endogenous. Therefore, this variable is correlated with the error term and this will lead to biased estimates of the it parameter ρ. In order to deal with the endogeneity of neighboring countries' environmental expenditure variables on the right hand side, we use an instrumental variable (IV) approach[25] to enable consistent estimation of Eq. (1) (Revelli (2002) and Bosch and Solé-Ollé (2007)). This method consists in finding variables that are correlated with neighbors' environmental expenditure choices but uncorrelated with the error term. An alternative approach would be to use maximum likelihood but as our panel data set is unbalanced, we cannot apply this method. We follow the approach of Kelejian et al. (2004) and Lee (2003) in choosing the set of instruments[26]. Formally, we use as instruments the set of exogenous variables X, various combinations of weighted average of neighbours' control variables (WX) and neighboring neighbors' weighted average control variables (W^2X), namely, $H = [X, WX, W^2X]$. However, these instruments are evaluated with two different statistics in order to confirm their validity. First, The Sargan test (or overidentifying restriction test) examines the hypothesis that the instruments are not correlated with the residuals. Second, we report F statistics on the identifying instruments of the first-stage regressions as a test of instrument quality.

Secondly, besides the simultaneity bias generated by the spatial lag of our dependent variable, another issue is related to the potentiel presence of additional endogenous variables when estimating our spatial interaction equations. In this study, we do not handle these potentiel endogenous variables. Nevertheless, to overcome these difficulties, we instead used temporal lagged variables (with a one-year time lag) of the main set of our explanatory variables (except the policy variables that are used at their current value).

Finally, another issue is related to parameter interpretation of explanatory variables. Since the

[25]They show that exogenous regressors X and different combinations of weighted average of neighbours' control variables, (i.e., their socio-economic characteristics WX and W^2X) are a valid set of instrumental variables for a generalised spatial two-stage least square procedure.

[26]Basically, two main approaches to tackle spatial simultaneity have been suggested: maximum likelihood (ML) and instrumental variables (IV) estimation techniques. The typical procedure under the IV approach in the spatial lag model is to regress WE on X and WX and to use fitted values WE as instruments for WE. There are several papers which use the instrumental variable approach, *e.g.* Ladd (1992), Kelejian and Robinson (1993), Brett and Pinkse (2000), Heyndels and Vuchelen (1998), Figlio et al. (1999), Buettner (2001) and Revelli (2001). The second method is based on the maximum likelihood (ML). Under this method, a nonlinear reduced form for (1) is computed by inverting the system. Examples of papers using maximum likelihood method: Case et al. (1993), Besley and Case (1995), Brueckner (1998), and Brueckner and Saavedra (2001) for instance.

estimated coefficients from a spatial lag model of equation (1) cannot be interpreted directly, we perform partial derivatives in line with LeSage and Pace (2009). Therefore, within the context of spatial autoregressive model of equation 1, the matrix of partial derivatives of E_{it} with respect the k-th explanatory variable of X_{it} in country i up to country N at a particular point in time t is:

$$\frac{\partial E_{it}}{\partial X_{it}} = [(I - \lambda W)^{-1}]\beta^{(k)} \tag{3.2}$$

These partial derivatives have some properties. Indeed, according to LeSage and Pace (2009), for spatial regression models, parameter interpretation of these variables becomes richer and more complicated in sense that a change in the explanatory variable for a single observation can potentially affect the dependent variable of all other observations. For example, a change in a particular explanatory variable in country i has a direct effect on that country, but also an indirect effect on the remaining countries. More specifically, the direct effects are measured by the average of the diagonal entries whereas the indirect effects are measured by the average of non-diagonal elements. Finally, the total effect is the sum of the direct and indirect impacts. In this paper, we only report results of direct impacts.

3.5 Results

Table 3.2 reports the results of the static spatial model (with country fixed effects) estimated by the instrumental variable estimation procedure, using 3 nearest neighbors as spatial weighting scheme. As mentioned above, we implement two different statistics (Sargan and F tests) in order to check the validity of the instruments used in the regressions. Test results suggest that our instruments meet the two necessary conditions that should be demanded of a good instrument: correlation with the environmental expenditure and orthogonality with the residuals.

Results are described below. Table 3.2 displays coefficients for estimations of environmental expenditures as dependent variable. Firstly, the estimates of spatial interaction parameters λ are statistically significant regardless different specifications (columns 1-3). The impact of interaction ranges from 0.5234 to 0.7398. This finding implies that OECD countries are engaging their strategic interactions with regard to environmental expenditure. In other words, countries tend to increase their environmental expenditure as a response to a rise in environmental expenditure of its neighbors. This finding is in line with Ermini and Santolini (2010) who show the existence of spatial environmental spending interactions among local councils in Italy.

Considering the influence of factors other than spatial environmental expenditure interactions, as mentioned in the previous section, correct interpretation of the parameter estimates in equation 1 requires to take into account the direct, indirect and total effects associated with changes in the regressors. Direct effects revealed by the static spatial model are reported in Table 3.2[27]. Inference is based on a bootstraping procedure. The results show that GDP per capita, the unemployment

Table 3.2: Estimations of environmental expenditures using 3 nearest neighbors as weight matrix:

	Dependent variable:		
	expenditure_knn		
	(1)	(2)	(3)
Neighboring environmental expenditures	0.7398***	0.5234**	0.7020***
	(0.2223)	(0.2105)	(0.2138)
	Direct impacts		
Lag(log(Tot_final_cons), k = 1)	1.3931	1.1629	1.4260
Lag(log(GDP_head), k = 1)	0.5175***	0.0288***	0.4961***
Lag(log(Population), k = 1)	−2.7827	0.2039	−3.2231
Lag(log(Pct_pop_young), k = 1)	3.1063	1.6493*	3.2148
Lag(log(Pct_pop_old), k = 1)	−3.0671***	−1.6189**	−3.1816***
Lag(log(Unemployment), k = 1)	0.2353***	0.1451***	0.2947***
PR		1.0433***	
CL			−0.1969***
Observations	300	293	293
R^2	0.1293	0.2328	0.1418
Adjusted R^2	0.0101	0.1249	0.0211
F Statistic	4.9121*** (df = 7; 263)	9.6382*** (df = 8; 256)	4.8359*** (df = 8; 256)
Note:			*p<0.1; **p<0.05; ***p<0.01

rate and civil liberties (CL) exert a positive impact on environmental expenditure, while the percentage of elderly population and political rights impact negatively environmental expenditures. More specifically, estimates reveal that environmental expenditure is higher as GDP per capita increase. This result is broadly in line with our prediction because the richer the country, the more it can spend in environmental sector. We also find that demographic factors influence environmental expenditure in several programmes. In particular, the percentage of elderly population has a direct negative effect on environmental expenditures while unemployment rate impacts positively country environmental expenditures. However, the population density does not significantly affect environmental expenditures. With respect to political variables, we find that there are globally significant impacts on environmental expenditures. For instance, the stronger the civil liberties (CL) are, the higher are the environmental expenditures (coefficient value equals to -0.1969). However, regarding political rights, we find an inverse result suggesting that higher are political rights (PR), lower are environmental expenditures with coefficient equals to 1.0433).

Secondly, we also check whether the mimicking behaviour observed in environmental expenditures can be generalised to main spending categories, namely energy sector or whether it reflects the presence of interaction among countries mainly within specific types of expenses. In this regard, we test the existence of spatial interactions related to energy R&D expenditures for 27 OECD countries using panel data for the period 1994–2014. We also employ instrumental variables technique on an unbalanced panel dataset. According to Hammadou et al. (2014), countries

[27] Tables in appendix provide the indirect and total effects from our spatial lag model. The total impact of explanatory variable X on dependent variable E is the sum of the direct and indirect impacts. The direct impact (i.e. $\frac{\partial E_i}{\partial X_{ik}}$ where X_{ik} denotes the k_{th} variable from the explanatory variable matrices) represents how changes in X_i affect E_i combined with how those changes in E_i affect E_j (i.e. other countries' environmental expenditures)and how that subsequently feedsback to E_i. The indirect impact (i.e. $\frac{\partial E_i}{\partial X_{jk}}$, where $i \neq j$) captures how X_j affects E_j and how that impact on E_j affects E_i.

might compete on R&D expenditure in order to attract (or avoid the migration of) firms or multinational corporations that are seeking a favorable and knowledge-intensive environment to locate their activities. Table 3.3 shows the coefficients for the spatial interactions of R&D total budget in energy. Similarly to the preceeding case, coefficients of spatial effects are significant. Hence, we do not reject spatial dependency among OECD countries when planning R&D budget for energy sector. This finding is closely related to Hammadou et al. (2014) that found the existence of strategic interactions in relation to R&D spending among European countries. However, with respect to this paper, the novelty of our approach is twofold. On the one hand, we analyze spatial interactions on R&D in energy sector. On the other hand, we examine these issues among OECD countries. Direct impact estimates in Table 3.3, display interesting features which are worth mentioning. Overall, we find that factors traditionally affecting public expenditure, such as GDP per capita, unemployment rate , the percentage of eldery population significantly affect the level of R&D spending in energy by OECD countries over 1994 and 2014. However, we do not find any significant impact of the population structure nor of the total final consumption.

Table 3.3: Estimations of RDD energy budget using 3 nearest neighbors as weight matrix:

	Dependent variable:		
	rdd_nrj_knn		
	(1)	(2)	(3)
Neighboring RDD energy budget	0.4479^{***}	0.4431^{***}	0.4317^{***}
	(0.1432)	(0.1443)	(0.1403)
	Direct impacts		
Lag(log(Tot_final_cons), k = 1)	-4.4304^{**}	-4.4252^{**}	-4.8542^{**}
Lag(log(GDP_head), k = 1)	-0.3426^{***}	-0.3398^{***}	-0.3474^{***}
Lag(log(Population), k = 1)	5.2355	5.2437	5.4241
Lag(log(Pct_pop_young), k = 1)	−13.5213	−13.5122	−13.9742
Lag(log(Pct_pop_old), k = 1)	-8.7175^{*}	-8.7169^{*}	−8.9905
Lag(log(Unemployment), k = 1)	-0.1775^{***}	-0.1754^{***}	-0.2351^{***}
PR		0.1358^{**}	
CL			-0.2355^{***}
Observations	133	133	133
R^2	0.7130	0.7136	0.7188
Adjusted R^2	0.6762	0.6741	0.6800
F Statistic	41.4134^{***} (df = 7; 117)	36.0457^{***} (df = 8; 116)	36.9791^{***} (df = 8; 116)
Note:			$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Finally, to investigate the presence of spatial interactions in CO2 emissions per capita, we also employ instrumental variable techniques using panel data model. Estimation results (Table 3.4) verify the existence of the spatial correlations in CO2 emissions across OECD countries. Indeed, the spatial autocorrelation parameter is statistically significant at 1% level (coefficient values range from 0.3306 to 0.4445), indicating the existence of spatial dependence in CO2 emissions among countries. This result suggests that air pollution in OECD countries exhibits significant positive spatial autocorrelation. This finding is in line with You and Lv (2018). We also find that the key determinants of CO2 emissions are GDP per capita, total final consumption of energy, population structure (percentages of young and old), unemployment rate and political variables such as political right and civil liberties. More specifically, the coefficient of population is significantly negative at the 1% level indicating that, more populated countries are associated with lower emissions, ceteris paribus. We also found that the final consumption of energy impacts positively and significantly CO2 emissions that is our expectation. In addition, polical variables such as political rights (PR) et civil liberties (CL), also impact positively CO2 emissions. In other words, higher are political rights (or civil liberties), higher are CO2 emissions.

Table 3.4: Estimations of CO2 emissions using 3 nearest neighbors as weight matrix:

	Dependent variable:		
	tot_co2_emissions_iea_knn		
	(1)	(2)	(3)
Neighboring CO2 emissions	0.4445***	0.3306***	0.4121***
	(0.0869)	(0.0910)	(0.0914)
	Direct impacts		
Lag(log(Tot_final_cons), k = 1)	0.7407***	0.7550***	0.7491***
Lag(log(GDP_head), k = 1)	−0.0444***	−0.0386***	−0.0519***
Lag(log(Population), k = 1)	0.0437***	−0.1122***	0.0118***
Lag(log(Pct_pop_young), k = 1)	0.0400***	0.0488***	0.0391***
Lag(log(Pct_pop_old), k = 1)	−0.0445***	−0.0572***	−0.0442***
Lag(log(Unemployment), k = 1)	−0.0274***	−0.0224***	−0.0254***
PR		−0.0709***	
CL			−0.0156***
Observations	553	535	535
R^2	0.5040	0.5180	0.5009
Adjusted R^2	0.4694	0.4831	0.4649
F Statistic	74.9033*** (df = 7; 516)	66.8848*** (df = 8; 498)	62.4822*** (df = 8; 498)
Note:			*p<0.1; **p<0.05; ***p<0.01

3.6 Robustness checks

As a robustness check, tables 3.5, 3.6 and 3.7 present IV estimates of the spatial lag dependence model for our three dependent variables using another definition of the concept of neighborhood. Rather than using a 3 nearest neighbors matrix, we use inverse distance as the weight matrix to explore spatial interdependence in our dependent variables among OECD countries. Whatever the specification, strategic interaction results are meaningful. As can be seen in table 3.5, with respect to spatial dependence using an inverse distance matrix, the results point to a spatial autocorrelation of the environmental expenditures. The estimate of the spatial lag coefficient λ is large and statistically significant in all specifications (columns 1-3). Indeed, in the SAR specification (table 3.5) relating to environmental expenditures, it was observed that the spatial lag is strong and positive with a coefficient varying from to 0.5201 to 0.6329, which means implies that the levels of environmental expenditures at the country level are positively and statistically related to the levels of environmental expenditures in adjacent countries. Regarding the set of independent variables, using the inverse distance weights matrix, our main results remain valid. For instance, table 3.5 shows evidence that GDP per capita, the percentage of eldery population, the unemployment rate impact significantly environmental expenditure levels. According to political variables, our previous results (using nearest neighbors) remains consistent.

Table 3.5: Estimations of environmental expenditures using inverse distance as weight matrix:

	Dependent variable:		
	expenditure_dist		
	(1)	(2)	(3)
Neighboring environmental expenditures	0.6329^{**}	0.5201^{**}	0.5738^{**}
	Direct impacts		
Lag(log(Tot_final_cons), k = 1)	1.5093	1.2414^{*}	1.5536
Lag(log(GDP_head), k = 1)	0.4998^{***}	-0.0127^{***}	0.4781^{***}
Lag(log(Population), k = 1)	−2.8971	0.2838	−3.3235
Lag(log(Pct_pop_young), k = 1)	2.9334	1.4729^{*}	3.0516
Lag(log(Pct_pop_old), k = 1)	-2.9193^{***}	-1.4492^{**}	-3.0453^{**}
Lag(log(Unemployment), k = 1)	0.2444^{***}	0.1498^{***}	0.3006^{***}
PR		1.1115^{***}	
CL			-0.1935^{***}
Observations	300	293	293
R^2	0.1019	0.2120	0.1164
Adjusted R^2	−0.0210	0.1012	−0.0078
F Statistic	3.6405^{***} (df = 7; 263)	8.4653^{***} (df = 8; 256)	3.8364^{***} (df = 8; 256)
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 3.6 shows the robustness check regarding R&D energy budget interaction analysis. The estimation results confirm the finding that countries take into account the R&D energy budget set by their neighbors when deciding the budget of energy R&D. Indeed, the spatial auto-regressive parameter (λ) is positive and strongly significant regardless of the underlying model (column 1-3) with coefficients varying from 0.3988 to 0.4171. The resulting significance of this parameter indicates the strength of the interactions existing between countries via the R&D energy budget. Hence SAR specifications of the first order spatial autoregressive coefficient on the lagged depen-

dent variable (λ) - using both 3 nearest neighbors and inverse distance as weight matrices - yield the same results. With regard to other covariates, there are additional findings worth mentioning. Overall, Table 3.6 shows significance for final consumption of energy, GDP per capita, the percentage of eldery population, the unemployment rate and political variables.

Table 3.6: Estimations of RDD energy budget using inverse distance as weight matrix:

	Dependent variable:		
	rdd_nrj_dist		
	(1)	(2)	(3)
Neighboring RDD energy budget	0.4171***	0.4127***	0.3988***
	(0.1432)	(0.1438)	(0.1408)
	Direct impacts		
Lag(log(Tot_final_cons), k = 1)	−4.2284**	−4.2221**	−4.6258*
Lag(log(GDP_head), k = 1)	−0.3351***	−0.3332***	−0.3344***
Lag(log(Population), k = 1)	5.4887	5.4959	5.6504
Lag(log(Pct_pop_young), k = 1)	−13.2213	−13.2178	−13.6271
Lag(log(Pct_pop_old), k = 1)	−8.5489*	−8.5554*	−8.7851*
Lag(log(Unemployment), k = 1)	−0.1600***	−0.1577***	−0.2124***
PR		0.1742***	
CL			−0.2128***
Observations	133	133	133
R^2	0.7039	0.7048	0.7094
Adjusted R^2	0.6659	0.6640	0.6693
F Statistic	39.6052*** (df = 7; 117)	34.5048*** (df = 8; 116)	35.2928*** (df = 8; 116)
Note:			*p<0.1; **p<0.05; ***p<0.01

Regarding the robustness analysis of CO2 emissions interactions, using the inverse distance weights matrix, our main results remain valid. For instance, Table 3.7 shows a positive and significant sign for spatial interaction parameter, confirming the spatial interactions among OECD countries for CO2 emissions. In other words, country seems to increase the level of their CO2 emissions in response to a rise in the level of CO2 emissions in their neighboring countries. In addition, with respect to the other covariates, Table 3.7 also shows that final consumption of energy, GDP per capita, the percentages of young and eldery population, the unemployment rate and political variables impact significantly CO2 emissions.

Table 3.7: Estimations of CO2 emissions using inverse distance as weight matrix:

	Dependent variable:		
	tot_co2_emissions_iea_dist		
	(1)	(2)	(3)
Neighboring CO2 emissions	0.4107***	0.3235***	0.3823***
	(0.0765)	(0.0788)	(0.0814)
	Direct impacts		
Lag(log(Tot_final_cons), k = 1)	0.7337***	0.7471***	0.7455***
Lag(log(GDP_head), k = 1)	−0.0453***	−0.0367***	−0.0532***
Lag(log(Population), k = 1)	0.0074***	−0.1465***	−0.0215***
Lag(log(Pct_pop_young), k = 1)	0.0501***	0.0637***	0.0498***
Lag(log(Pct_pop_old), k = 1)	−0.0527***	−0.0708***	−0.0530***
Lag(log(Unemployment), k = 1)	−0.0258***	−0.0198***	−0.0236***
PR		−0.0747***	
CL			−0.0152***
Observations	553	535	535
R^2	0.5072	0.5236	0.5037
Adjusted R^2	0.4729	0.4891	0.4678
F Statistic	75.8781*** (df = 7; 516)	68.3966*** (df = 8; 498)	63.1782*** (df = 8; 498)
Note:			*p<0.1; **p<0.05; ***p<0.01

3.7 Conclusions

In this study, static spatial models are employed to address question of whether OECD countries engage in strategic interactions regarding the environmental expenditures. Based on panel data of 30 OECD countries over the period of 1994–2014, clear evidence has been found that support the existence of significant and positive spatial interactions: countries act strategically regarding environmental spending by providing more environmental expenditure as a response to the increase of environmental expenditure of their neighboring cities. We also find evidence of spatial correlation of CO2 emissions suggesting that an increase in CO2 emissions of neighboring countries would cause the rising of CO2 emissions in the country. Overall, our spatial interaction results are in line with the small literature on public spending interactions among governments (for instance Ermini and Santolini (2010) for spatial environmental spending interactions among local councils in Italy, Hammadou et al. (2014) in investigating R&D interactions among European countries and You and Lv (2018) for spatial interactions on CO2 emissions in a panel of 83 countries). The results in our paper support the conjecture that countries act interdependently when they formulate policy choices related to environmental expenditures, R&D in energy sector and CO2 emissions.

Study on environmental expenditures is useful for various reasons. First, it facilitate international comparisons on trends in environmental expenditure information by highlighting countries behaviors. Second, it may assist in the development of more effective environmental policies and regulations including national and regional budgetary decisions and the design of economic and administrative instruments for environmental protection. Finally, it provides policymakers with indicators and descriptive statistics to monitor these interactions and also a database for strategic planning and policy analysis to identify more sustainable paths of development. Overall, investigation of the determinants of different countries' behaviors and expected outcomes is important in terms of dependence/independence in environmental expenditure decisions. In this regards, it is interesting to examine these issues from both on effective expenditures and a system of innovation perspective (in particular R&D budget in energy sector). Further, our spatial interaction results about R&D energy budget highlighting that policy-makers of countries may imitate their neighboring countries when they consider that investors in energy sector are likely to compare countries in terms of their economic environment to locate their activities. In this way, the mimicking behavior of policy-makers may allow countries to avoid capital and firms' migration.

Regarding air pollution, as country CO2 emissions could be considered as environmental performance, it appears interesting to investigate the spatial dependence of CO2 emissions among countries for a number of reasons. First, spatial interactions in CO2 emissions among economies may arise as a consequence of countries strategic response to transboundary pollution flows as governments might strategically manipulate environmental standards in an attempt to attract capital, or for trade purposes (Rios and Gianmoena (2018)). As results, CO2 emissions might be spatially correlated due to the mimicking effects. Indeed, countries mimicking each others' environmental policies which may lead to similar environmental quality along the spatial dimension. Furthermore, if environmental performance (CO2 emissions as proxy) is judged by consumers by making comparisons among countries, they may adjust their own environmental performance in response to that of other countries (occurrence of yardstick competition). An other reason justifying spatial emission interactions is related to policy sense. In this purpose, according to Aldy (2005), geographic distribution of CO2 emissions does not affect the global climatic impact, but it does affect the political economy of negotiating multilateral agreements. In this way, CO2 emission intensity may offer a more equitable measure for negotiating multilateral agreements.

To be sure, we faced some significant limitations while conducting this analysis. Firstly, one of the principle problems is in regards to missing data. Second, our model may be greatly improved by threating stringently a potentiel endogenous of some variables in a right-end-side of our estimation equation... Further research considering these issues would contribute to the validation of our main results.

3.8 Appendices

3.8.1 Appendix C1: Correlation matrix

Figure 3.3: Correlation matrix

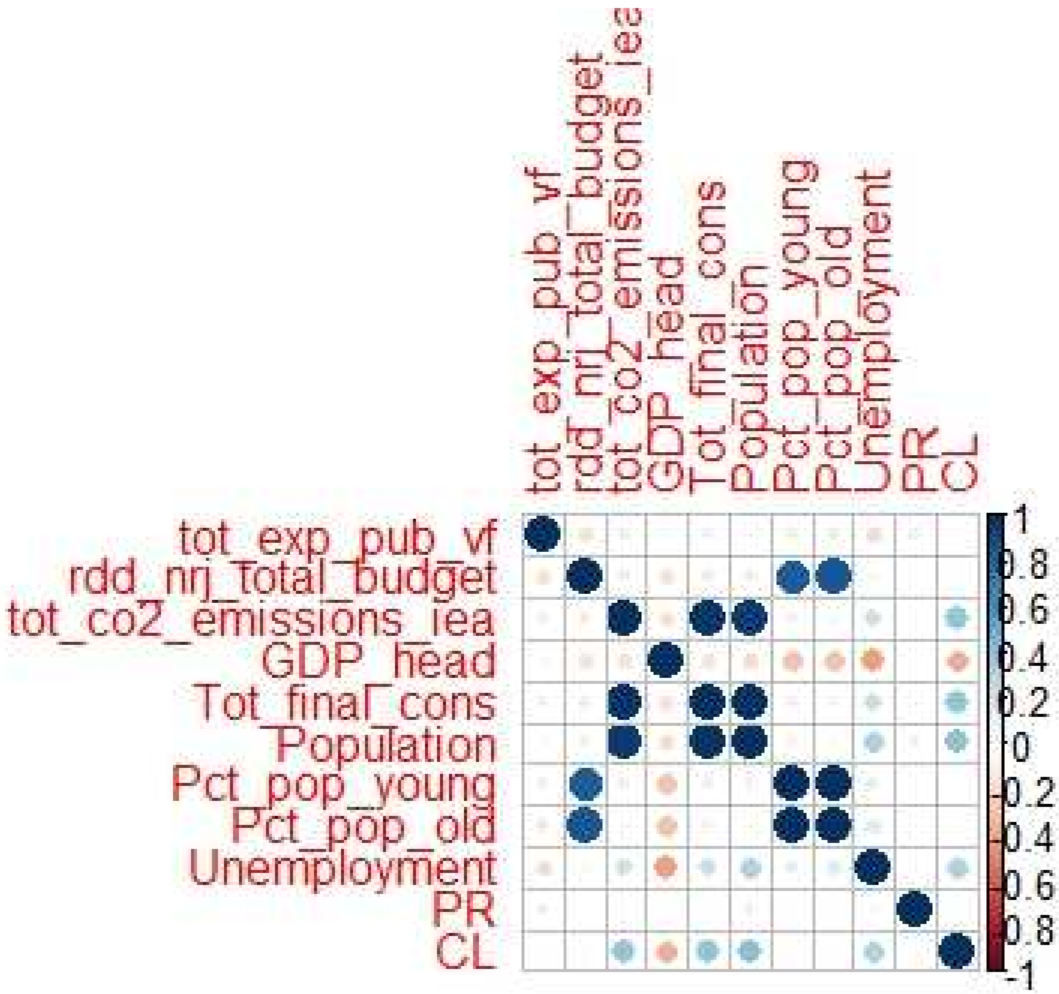


Table 3.8: Estimations of environmental expenditures using 3 nearest neighbors as weight matrix:

	Dependent variable:		
	expenditure_knn		
	(1)	(2)	(3)
Neighboring environmental expenditures	0.7398***	0.5234**	0.7020***
	(0.2223)	(0.2105)	(0.2138)
Lag(log(Tot_final_cons), k = 1)	1.3931**	1.1629**	1.4260**
	(0.5524)	(0.5065)	(0.5537)
Lag(log(GDP_head), k = 1)	0.5175**	0.0288	0.4961*
	(0.2628)	(0.2511)	(0.2549)
Lag(log(Population), k = 1)	−2.7827*	0.2039	−3.2231**
	(1.5514)	(1.4766)	(1.5520)
Lag(log(Pct_pop_young), k = 1)	3.1063***	1.6493	3.2148***
	(1.0927)	(1.0060)	(1.1177)
Lag(log(Pct_pop_old), k = 1)	−3.0671***	−1.6189	−3.1816***
	(1.0766)	(0.9975)	(1.1042)
Lag(log(Unemployment), k = 1)	0.2353	0.1451	0.2947*
	(0.1610)	(0.1427)	(0.1674)
PR		1.0433***	
		(0.2773)	
CL			−0.1969*
			(0.1164)
Observations	300	293	293
R^2	0.1293	0.2328	0.1418
Adjusted R^2	0.0101	0.1249	0.0211
F Statistic	4.9121*** (df = 7; 263)	9.6382*** (df = 8; 256)	4.8359*** (df = 8; 256)
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 3.9: Estimations of environmental expenditures using inverse distance as weight matrix:

	Dependent variable:		
	expenditure_dist		
	(1)	(2)	(3)
Wlogtot_exp_pub_vf	0.6329**	0.5201**	0.5738**
	(0.2662)	(0.2551)	(0.2579)
Lag(log(Tot_final_cons), k = 1)	1.5093***	1.2414**	1.5536***
	(0.5656)	(0.5173)	(0.5668)
Lag(log(GDP_head), k = 1)	0.4998*	−0.0127	0.4781*
	(0.2717)	(0.2507)	(0.2626)
Lag(log(Population), k = 1)	−2.8971*	0.2838	−3.3235**
	(1.6453)	(1.5341)	(1.6324)
Lag(log(Pct_pop_young), k = 1)	2.9334***	1.4729	3.0516***
	(1.0824)	(0.9608)	(1.1077)
Lag(log(Pct_pop_old), k = 1)	−2.9193***	−1.4492	−3.0453***
	(1.0666)	(0.9528)	(1.0963)
Lag(log(Unemployment), k = 1)	0.2444	0.1498	0.3006*
	(0.1682)	(0.1482)	(0.1736)
PR		1.1115***	
		(0.2829)	
CL			−0.1935
			(0.1179)
Observations	300	293	293
R^2	0.1019	0.2120	0.1164
Adjusted R^2	−0.0210	0.1012	−0.0078
F Statistic	3.6405*** (df = 7; 263)	8.4653*** (df = 8; 256)	3.8364*** (df = 8; 256)
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 3.10: Estimations of RDD energy budget using 3 nearest neighbors as weight matrix:

	Dependent variable:		
	rdd_nrj_knn		
	(1)	(2)	(3)
Wlogrdd_nrj_total_budget	0.4479***	0.4431***	0.4317***
	(0.1432)	(0.1443)	(0.1403)
Lag(log(Tot_final_cons), k = 1)	−4.4304***	−4.4252***	−4.8542***
	(0.6915)	(0.6904)	(0.7264)
Lag(log(GDP_head), k = 1)	−0.3426	−0.3398	−0.3474
	(0.2444)	(0.2440)	(0.2456)
Lag(log(Population), k = 1)	5.2355***	5.2437***	5.4241***
	(0.8541)	(0.8539)	(0.8687)
Lag(log(Pct_pop_young), k = 1)	−13.5213***	−13.5122***	−13.9742***
	(1.4836)	(1.4818)	(1.4867)
Lag(log(Pct_pop_old), k = 1)	−8.7175***	−8.7169***	−8.9905***
	(0.9535)	(0.9525)	(0.9530)
Lag(log(Unemployment), k = 1)	−0.1775	−0.1754	−0.2351
	(0.1736)	(0.1734)	(0.1800)
PR		0.1358	
		(0.2350)	
CL			−0.2355
			(0.1534)
Observations	133	133	133
R^2	0.7130	0.7136	0.7188
Adjusted R^2	0.6762	0.6741	0.6800
F Statistic	41.4134*** (df = 7; 117)	36.0457*** (df = 8; 116)	36.9791*** (df = 8; 116)
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 3.11: Estimations of RDD energy budget using inverse distance as weight matrix:

	Dependent variable:		
	rdd_nrj_dist		
	(1)	(2)	(3)
Wlogrdd_nrj_total_budget	0.4171***	0.4127***	0.3988***
	(0.1432)	(0.1438)	(0.1408)
Lag(log(Tot_final_cons), k = 1)	−4.2284***	−4.2221***	−4.6258***
	(0.7417)	(0.7402)	(0.7793)
Lag(log(GDP_head), k = 1)	−0.3351	−0.3332	−0.3344
	(0.2573)	(0.2566)	(0.2574)
Lag(log(Population), k = 1)	5.4887***	5.4959***	5.6504***
	(0.8540)	(0.8531)	(0.8683)
Lag(log(Pct_pop_young), k = 1)	−13.2213***	−13.2178***	−13.6271***
	(1.4800)	(1.4783)	(1.4779)
Lag(log(Pct_pop_old), k = 1)	−8.5489***	−8.5554***	−8.7851***
	(0.9505)	(0.9494)	(0.9475)
Lag(log(Unemployment), k = 1)	−0.1600	−0.1577	−0.2124
	(0.1760)	(0.1759)	(0.1824)
PR		0.1742	
		(0.2310)	
CL			−0.2128
			(0.1566)
Observations	133	133	133
R^2	0.7039	0.7048	0.7094
Adjusted R^2	0.6659	0.6640	0.6693
F Statistic	39.6052*** (df = 7; 117)	34.5048*** (df = 8; 116)	35.2928*** (df = 8; 116)
Note:			*p<0.1; **p<0.05; ***p<0.01

3.8.2 Appendix C2: Estimation results for environmental expenditures using other weighting schemes:

3.8.3 Appendix C3: Estimation results for RDD energy budget using other weighting schemes:

3.8.4 Appendix C4: Estimation results for CO2 emissions using other weighting schemes:

Table 3.12: Estimations of CO2 emissions using 3 nearest neighbors as weight matrix:

	Dependent variable:		
	tot_co2_emissions_iea_knn		
	(1)	(2)	(3)
Wlogtot_co2_emissions_iea	0.4445***	0.3306***	0.4121***
	(0.0869)	(0.0910)	(0.0914)
Lag(log(Tot_final_cons), k = 1)	0.7407***	0.7550***	0.7491***
	(0.0640)	(0.0653)	(0.0664)
Lag(log(GDP_head), k = 1)	−0.0444**	−0.0386**	−0.0519**
	(0.0187)	(0.0190)	(0.0205)
Lag(log(Population), k = 1)	0.0437	−0.1122	0.0118
	(0.0834)	(0.0899)	(0.0861)
Lag(log(Pct_pop_young), k = 1)	0.0400	0.0488	0.0391
	(0.0407)	(0.0411)	(0.0416)
Lag(log(Pct_pop_old), k = 1)	−0.0445	−0.0572	−0.0442
	(0.0398)	(0.0401)	(0.0406)
Lag(log(Unemployment), k = 1)	−0.0274**	−0.0224	−0.0254*
	(0.0135)	(0.0138)	(0.0139)
PR		−0.0709***	
		(0.0164)	
CL			−0.0156*
			(0.0094)
Observations	553	535	535
R^2	0.5040	0.5180	0.5009
Adjusted R^2	0.4694	0.4831	0.4649
F Statistic	74.9033*** (df = 7; 516)	66.8848*** (df = 8; 498)	62.4822*** (df = 8; 498)
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 3.13: Estimations of CO2 emissions using inverse distance as weight matrix:

	Dependent variable:		
	tot_co2_emissions_iea_dist		
	(1)	(2)	(3)
Wlogtot_co2_emissions_iea	0.4107***	0.3235***	0.3823***
	(0.0765)	(0.0788)	(0.0814)
Lag(log(Tot_final_cons), k = 1)	0.7337***	0.7471***	0.7455***
	(0.0646)	(0.0652)	(0.0667)
Lag(log(GDP_head), k = 1)	−0.0453**	−0.0367**	−0.0532***
	(0.0183)	(0.0184)	(0.0200)
Lag(log(Population), k = 1)	0.0074	−0.1465*	−0.0215
	(0.0834)	(0.0872)	(0.0856)
Lag(log(Pct_pop_young), k = 1)	0.0501	0.0637	0.0498
	(0.0412)	(0.0418)	(0.0424)
Lag(log(Pct_pop_old), k = 1)	−0.0527	−0.0708*	−0.0530
	(0.0401)	(0.0406)	(0.0412)
Lag(log(Unemployment), k = 1)	−0.0258*	−0.0198	−0.0236*
	(0.0133)	(0.0135)	(0.0137)
PR		−0.0747***	
		(0.0159)	
CL			−0.0152
			(0.0093)
Observations	553	535	535
R^2	0.5072	0.5236	0.5037
Adjusted R^2	0.4729	0.4891	0.4678
F Statistic	75.8781*** (df = 7; 516)	68.3966*** (df = 8; 498)	63.1782*** (df = 8; 498)
Note:			*p<0.1; **p<0.05; ***p<0.01

Conclusion générale

Dans cette thèse, nous avons exploré la question du fédéralisme fiscal appliqué aux questions environnementales sous l'angle des interactions spatiales entre gouvernements, i.e., sous l'angle des interdépendances entre différentes juridictions dans la mise en oeuvre des politiques environnementales et plus spécifiquement des politiques fiscales de l'énergie. Ces trois chapitres témoignent de l'importance de la prise en compte de ces interactions entre gouvernements dans la mise en oeuvre des politiques environnementales, alors même que cette dimension reste relativement peu explorée dans la littérature. Les deux premiers chapitres se sont focalisés sur la fiscalité énergétique àla fois d'un point de vue théorique et empirique. Dans le dernier chapitre, nous nous sommes focalisés sur l'étude des interactions spatiales dans les dépenses environnementales. En guise de synthèse globale, cette thèse tend à confirmer l'hypothèse d'existence d'interactions spatiales entre gouvernements dans l'exécution des décisions relatives à l'environnement. En d'autres termes, les décisions budgétaires environnementales prises par les pouvoirs publics, à la fois au niveau local et fédéral, dépendent de celles prises par leurs voisins. Ignorer ces comportements stratégiques peut compromettre les objectifs environnementaux.

Dans le premier chapitre, nous avons testé les interactions fiscales spatiales au niveau départemental d'un point de vue empirique pour la fiscalité énergétique. Nos résultats pourraient guider les pouvoirs publics dans leurs décisions quant à l'échelon qui devrait prélever la fiscalité énergétique. D'une part, nous avons montré l'existence d'interactions spatiales entre départements français dans la détermination de la vignette automobile. Nos résultats d'estimation montrent un comportement mimétique des départements français dans la gestion de cet impôt indirect local qu'est la vignette. D'autre part, nous avons mis en évidence l'importance des interdépendances entre différents instruments fiscaux, à savoir entre la fiscalité directe locale (composée des "quatre vieilles" que sont la taxe d'habitation, la taxe professionnelle, la taxe sur le foncier bâti et celle sur le foncier non bâti) et la fiscalité indirecte locale à travers la vignette automobile. Plus spécifiquement, nous avons trouvé que la taxe professionnelle et la taxe sur le foncier bâti sont complémentaires à la vignette automobile tandis que la taxe d'habitation et la taxe sur le foncier non bâti sont des substituts à la vignette. Ce résultat de substitution entre instruments de la fiscalité locale est intéressant puisqu'il renvoie au mécanisme compensatoire des décideurs publics locaux. Ce mécanisme de compensation entre instruments de taxation est un levier important dans la réussite d'une fiscalité locale pour plusieurs raisons. Du point de vue des assujettis, à travers ce mécanisme compensatoire, ces derniers perçoivent un allégement fiscal et *in fine* cela facilite l'acceptabilité de cette taxe locale. Du point de vue des décideurs, une mesure compensatoire entre différents instruments serait une aubaine puisqu'ils peuvent compenser les pertes de recettes suite à une diminution d'une taxe locale, en augmentant le taux de l'instrument fiscal de substitution. Dans le cadre énergétique, cette logique de compensation pourrait ainsi servir d'une part à améliorer les recettes fiscales énergétiques sans alourdir le fardeau fiscal qui pèse sur les contribuables, d'autre part. En résumé, ce chapitre est novateur en ce sens qu'il teste pour la première fois l'hypothè se d'interdépendance spatiale à travers un instrument de fiscalité indirecte locale, en l'occurrence la vignette automobile, et analyse les interdépendances entre les différents instruments de la fiscalité locale.

Dans le deuxième chapitre, nous avons analysé le cadre théorique des interactions entre gouvernements du point de vue de la fiscalité énergétique, ce qui permet d'apporter des pistes de réflexion quant à l'organisation souhaitable du fédéralisme fiscal énergétique. Plus précisément, nous avons étudié les interactions entre gouvernements de deux échelons différents, i.e., un gouvernement fédéral et des gouvernements régionaux, dans leurs choix de fiscalité. Une originalité de ce chapitre réside dans la taxation de deux bases fiscales (capital et énergie) qui sont interdépendantes. En particulier, nos résultats montrent d'abord que le compromis fédéral entre la taxation du capital et la taxation de l'énergie ne dépend que de l'offre exogène relative en énergie et en capital. Ensuite, le compromis entre la taxation du capital et celle de l'énergie est beaucoup plus complexe, car il dépend également de la comparaison des effets de distorsion de ces taxes sur le bien public régional et la qualité de l'environnement, ainsi que sur l'interdépendance des deux taxes. Enfin, nous trouvons également une substitution entre les taxes fédérales et régionales, quelle que soit l'interdépendance de ces deux taxes, ce qui implique que le gouvernement fédéral augmente un taux d'imposition donné en réponse à la diminution de l'un des deux taux d'impôt régionaux.

Dans le dernier chapitre, nous avons évalué les comportements des gouvernements sous l'angle des dépenses environnementales afin de tester l'existence d'interactions spatiales *via* ces dépenses. Nos résultats montre en particulier l'existence d'une interdépendance spatiale des pays de l'OCDE dans le choix de leurs dépenses environnementales. Ceci a des implications en termes de politiques publiques en ce sens qu'un comportement mimétique des pays de l'OCDE peut s'opérer à l'encontre des enjeux environnementaux. En d'autres termes, certains pays peuvent pratiquer des normes environnementales peu rigoureuses afin d'attirer des capitaux étrangers au détriment des pays voisins avec des normes environnementales strictes. Ces derniers, anticipant ce comportement, peuvent s'aligner sur les normes environnementales des premiers afin d'éviter des fuites de capitaux, un comportement allant à l'encontre des enjeux environnementaux. Les décideurs publics à l'échelle internationale doivent être conscients de ce type de comportement dans le cadre des accords internationaux dédiés à la protection de l'environnement. Nous avons également testé l'hypothèse d'interdépendance spatiale des pays de l'OCDE à travers les émissions de CO2 et les dépenses en R&D du secteur de l'énergie. Ces deux analyses viennent en complément et permettent d'une part, d'analyser la portée de nos résultats obtenus pour les dépenses environnementales sur un secteur spécifique (i.e l'énergie). En d'autres termes, le secteur de l'énergie étant une composante majeure des dépenses environnementales, une analyse d'interactions spatiales dans ce secteur a permis de fournir des informations intéressantes sur le caractère général ou spécifique de nos résultats d'interactions sur les dépenses. En outre, une analyse des interactions sur les dépenses en R&D permet également de fournir des informations aux décideurs publics afin de les aider dans leurs décisions d'investissements en R&D du secteur de l'énergie. D'autre part, les émissions de CO2 constituent de nos jours un outil de régulation environnementale. A cet égard, une analyse des résultats des pays dans ce domaine est important dans une perspective de lutte contre le changement climatique, pour l'amélioration de la qualité de l'air, la préservation de la biodiversité... A travers ces deux problématiques, nous avons montré l'existence d'interactions spatiales des pays de l'OCDE. Ce résultat implique que les pays de l'OCDE intègrent les décisions prises par leurs voisins dans la mise en oeuvre de leurs politiques de régulation environnementale (à travers les émissions de CO2) et de leurs décisions d'investissements en R&D du secteur de l'énergie.

Si cette thèse met en évidence des interactions spatiales, elle n'en identifie toutefois pas la source, un objectif qui peut s'avère difficile Agrawal (2013); Eugster et al. (2013); Lyytikäinen (2012); Reback (2007). Certains auteurs recourent à des expériences naturelles ou des régressions sur discontinuité (Gibbons and Overman, 2012) . Nous pourrions notamment utiliser la rupture liée à la décentralisation de la vignette automobile en 1984, la vignette ayant d'abord fait l'objet d'une gestion au niveau de l'Etat depuis sa création en 1956 jusqu'à sa décentralisation. A partir de 1984, les départements avaient l'autonomie de déterminer le montant de la vignette jusqu'à sa suppression en 2000 pour les véhicules des particuliers. Dès lors, une régression sur discontinuité serait très utile dans une optique d'analyse du comportement des différents échelons dans la gestion de cet impôt. Une piste d'amélioration intéressante consisterait également à évaluer l'impact de la vignette automobile sur le parc automobile français. En effet, dans l'analyse d'interactions des départements *via* la vignette, nous avons exclu certaines variables telles que le nombre d'immatriculations, le nombre de permis de conduire délivrés par les départements car ces variables sont fortement corrélées au montant de la vignette. Ainsi, une analyse plus approfondie en recourant à des instruments valides permettrait d'apporter des éléments de réponse de l'impact du parc automobile français sur la vignette automobile et inversement. Par ailleurs, le recours aux méthodes de l'économétrie spatiale s'est fait en première analyse sans au préalable justifier les fondements théoriques qui sous-tendent la démarche empirique (Corrado and Fingleton, 2012). A cet effet, une piste d'amélioration de nos travaux empiriques serait de proposer un cadre théorique adapté à notre modélisation empirique.

Notre cadre théorique du chapitre 2 est toutefois relativement proche, avec la taxation de deux bases fiscales interdépendantes. Plusieurs extensions de notre modélisation théorique peuvent servir de pistes d'amélioration de l'architecture du fédéralisme fiscal énergétique. D'abord, certaines hypothèses peuvent être levées afin de gagner en généralité. En effet, les principaux résultats sont basés sur des hypothèses relatives aux fonctions d'utilité et de production. Dès lors, nous pourrions proposer des formes plus générales des fonctions d'utilité et de production afin d'analyser les interactions entre les différents échelons de gouvernements. Ensuite, l'hypothèse selon laquelle la fédération et les gouvernements régionaux sont bienveillants peut être levée afin de prendre en considération des comportements de type Léviathan. Dans la même perspective, ce chapitre théorique est mené dans un cadre parfaitement symétrique. Une nouvelle piste serait d'évaluer les conséquences des comportements asymétriques dans l'analyse de l'architecture du fédéralisme fiscal énergétique. Enfin, nous prévoyons de poursuivre cette analyse théorique en proposant une simulation dans une optique d'interprétation de nos résultats.

Concernant l'étude empirique portant sur les dépenses environnementales, nous avons été confrontés à certaines difficultés qui limitent la portée de nos résultats. Premièrement, la présence de valeurs manquantes dans la base nous a contraints à adopter la méthode des variables instrumentales, laquelle est dépendante de la présence d'instruments valides. Dès lors, une première piste d'amélioration de ce travail empirique sur les dépenses environnementales serait d'améliorer notre base de données en réduisant autant que possible les données manquantes et, dans la mesure où ces valeurs ne sont pas *missing at random*, de proposer un modèle de sélection pour gérer au mieux les valeurs manquantes restantes. Deuxièmement, il subsiste dans notre modélisation empirique un biais de simultanéité qui n'est pas intégralement traité du fait de l'absence d'instruments valides pouvant nous permettre de lever totalement ce biais d'endogénéité. Nous avons contourné cette difficulté en exploitant notre base de données en panel, plus particulièrement en retardant d'une voire deux années les variables qui étaient susceptibles d'être endogènes. Cependant, il est important de noter que cette démarche n'est valable que s'il n'y a pas beaucoup d'inertie des variables concernées.

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