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Three essays on environmental economics:

Remanufacturing, Movements of Waste, and Democracy

A thesis presented

by

Sophie Bernard

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Sommaire

Chapitre 1 : Remanufacturing : Le remanufacturing est une forme de recyclage où des biens durables usagés sont remis à neuf. Tout en consommant moins d'énergie et de ressources, les biens remanufacturés sont produits à une fraction du coût original et émettent moins de pollution. Ce papier présente un modèle théorique de remanufacturing où un duopole de manufacturiers originaux produit un composant d'un bien final. Ce composant devant être changé, un marché secondaire est créé. Une réglementation environnementale déterminant un niveau minimal de remanufacturabilité est introduite au modèle. Les principaux résultats indiquent qu'un planificateur social pourrait substituer la réglementation environnementale par la collusion des firmes sur le niveau de remanufacturabilité. Cependant, lorsqu'une réglementation environnementale est prévue, la collusion devrait être réprimée puisque la compétition s'accorde mieux avec une intervention publique. Un des résultats coïncide aussi avec l'hypothèse de Porter.

Chapitre 2 : Mouvements transfrontaliers des déchets : Dans un modèle stylisé de commerce international, un monopole du Nord exporte, avec un potentiel de gain à l'échange, des biens de seconde-main qui seront réutilisés comme biens intermédiaires par une firme représentative du Sud. Le degré de réutilisabilité des produits en fin de vie est une variable de choix importante dans le Nord puisqu'en raison d'un manque de vigilance internationale, l'expédition illégale de biens non-réutilisables s'immisce avec l'exportation légitime de biens. Le modèle explore les causes du mouvement illégal des déchets en portant une attention particulière à la réglementation sur la gestion des déchets telle que la directive européenne sur les déchets d'équipements électriques et électroniques. Sous certaines conditions faibles, les résultats indiquent qu'une réglementation plus stricte dans le pays du Nord incite le monopole à réduire la réutilisabilité de ses produits. Traduit par un plus grand flux de déchets vers les pays en développement, ce résultat procure une voie alternative à l'hypothèse du paradis des pollueurs.

Chapitre 3 : La démocratie est-elle bénéfique pour l'environnement ? Le rôle de la protection privée : On étudie la question soulevée dans le titre dans le contexte d'économies ouvertes où le commerce et le bien-être dépendent de l'amplitude avec laquelle la réglementation permet à l'environnement d'être utilisé comme intrant à la production. Dans ces économies, on introduit aussi l'existence de protections privées contre la pollution, disponibles à un coût. Les gouvernements peuvent aussi contrôler l'ouverture au commerce de façon directe, ainsi que de façon indirecte à travers la réglementation environnementale. Dans ce cadre, on compare le degré de réglementation et le niveau de pollution émergeant à l'équilibre d'un ensemble de régimes politiques variant de l'autocratie à la démocratie. La réponse à la question n'est pas simple puisque les citoyens les mieux nantis des pays démocratiques peuvent préférer les revenus supplémentaires provenant d'une grande liberté au commerce et d'une production peu réglementée.

Abstract

Chapter 1: Remanufacturing: Remanufacturing is a form of recycling where used durable goods are refurbished to a condition comparable to new products. With reduced energy and resource consumption, remanufactured goods are produced at a fraction of the original cost and with lower emissions of pollution. This paper presents a theoretical model of remanufacturing where a duopoly of original manufacturers produces a component of a final good. The component needing to be replaced creates an aftermarket. An environmental regulation assessing a minimum level of remanufacturability is also introduced. The main results indicate that a social planner could use collusion of the firms on the level of remanufacturability as a substitute for environmental regulation. However, if an environmental regulation is to be implemented, collusion should be repressed since competition supports the public intervention better. One of the results also coincides with the Porter Hypothesis.

Chapter 2: Transboundary movements of waste: In a stylized model of international trade, a monopolist in the North exports second-hand products to a representative firm in the South to be reused as intermediate goods, with potential trade gains. The degree of reusability of waste products is a crucial choice variable in the North. This is because with a lack of international vigilance, non-reusable waste can be mixed illegally with the reusable waste. I explore the driving forces for the movement of illegal waste, paying particular attention to the role of local waste regulations, such as the EU's Waste Electrical and Electronic Equipment directive. Under mild conditions, it is shown that increased regulation stringency in the North leads its firm to reduce the degree of reusability of its products. As a result, the flow of non-reusable waste to the South increases, providing another channel for the Pollution Haven Hypothesis.

Chapter3: Is Democracy good for the environment? The role of private mitigation efforts: We study the question posed in the title in the context of open economies where trade and welfare depend on the extent to which regulation permits the environment to be used as an input in production, and where individuals may privately mitigate the consequences of pollution at a cost. Governments may also manage the openness of the economy to trade directly as well as indirectly via environmental regulation. In this framework, we compare the degree of regulatory stringency and the level of pollution that emerge in the equilibria of a set of political regimes that range from autocratic to fully competitive or democratic. The answer to the question is not straightforward in this investigation because many well-off citizens in democratic countries may prefer the higher gross incomes that come with freer trade and unregulated production.

À ma mère, Roseline Arsenault.

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Contents

Introduction générale

Cette thèse est constituée de trois chapitres, divisés en deux sujets distincts d'économie de l'environnement. Les deux premiers chapitres, *Remanufacturing* et *Mouvements transfrontaliers des déchets*, explorent ce qui arrive aux produits à la fin de leur vie. Ils incorporent l'étude de réglementations sur les designs écologiques améliorant la réutilisation des produits. Le troisième chapitre, intitulé *La démocratie est-elle bénéfique pour l'environnement ? Le rôle de la protection privée*, relie environnement, commerce et démocratie.

Les deux premiers articles étudient la réutilisation des déchets. Cette activité est désirable d'un point de vue environnemental car elle réduit la quantité de déchets post-consommation, ainsi que l'utilisation de matériaux bruts. En plus de ces bénéfices environnementaux, la réutilisation des déchets donne la possibilité de satisfaire les besoins de consommation d'une plus grande partie de la population. En effet, les produits de seconde-main, différenciés des produits neufs en terme de qualité et de génération technologique, sont plus accessibles aux individus à faibles revenus. La différenciation des produits amène la segmentation des marchés, ce qui joue un rôle crucial dans l'environnement compétitif où évoluent les producteurs et les recycleurs.

La compétition est le thème du premier chapitre, *Remanufacturing*. Le remanufacturing est un type de recyclage où les produits sont remis à neuf. La particularité de ce marché vient du fait que les produits en fin de vie peuvent être remanufacturés à faible coût et revendus. Typiquement, ils sont remanufacturés à un coût variant de 35 à 60 % du coût original, alors qu'ils sont revendus à 60-70 % du prix du nouveau produit [Giuntini et Gaudette 2003]. Cette possibilité de profit attire non seulement les producteurs originaux sur le marché secondaire, mais aussi des remanufacturiers indépendants. Cette caractéristique a aussi été observée dans le marché du recyclage des matériaux bruts. Par exemple, les producteurs d'aluminium sont volontairement impliqués dans l'industrie du recyclage car « l'aluminium a tellement de valeur et est si facile à recycler » [traduction de l'auteur, www.alcoa.com].

Le processus du remanufacturing est un défi pour l'ingénierie et la gestion car, non seulement les produits doivent être conçus afin d'être aisément ouverts, nettoyés et réparés, mais ils doivent aussi retourner de façon centralisée vers les remanufacturiers après avoir été consommés. Ainsi, ce sujet est bien étudié en ingénierie et en gestion comme en témoigne la littérature florissante sur la logistique inverse, la planification des stocks, la demande et le retour du matériel, ainsi que les études de cas.[1] Néanmoins, cette industrie de 60-100 milliards de dollars reste pratiquement absente de la littérature économique. Seulement une poignée d'études considèrent l'effet de l'intervention du gouvernement sur le remanufacturing [Webster et Mitra 2007; Mitra et Webster 2008]. Suite à l'exploration détaillée du marché états-unien, Lund explique qu'en raison de la variété des produits et la petite taille des acteurs, cette industrie reste « virtuellement invisible » aux yeux des décideurs politiques. Conséquemment, les activités de remanufacturing restent vaguement définies, sous-estimées et sous-réglementées [Lund 1984, Hauser et Lund 2003].

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[1] Par exemple, Ferrer (1997), Kiesmuller et Laan (2001), Majumder et Groenevelt (2001), Lebreton et Tuma (2006), Ferrer et Swaminathan (2006), Chung et We (2008).

Ce premier chapitre est inspiré de l'industrie des alternateurs où l'abolition de l'amiante dans la production a rendu le remanufacturing des alternateurs économiquement viable. Lorsqu'on regarde l'histoire de la production des alternateurs, l'implémentation de la réglementation sur l'amiante et les activités de remanufacturing dans cette industrie, une question légitime est : Pourquoi les producteurs d'alternateur n'ont-ils pas retiré volontairement l'amiante de leur production si le remanufacturing est si profitable aujourd'hui ? En répondant à cette question, j'ai eu accès à des informations privilégiées par l'entremise de contacts personnels provenant de l'industrie.

L'industrie est modélisée comme suit. Un duopole de producteurs originaux détient des informations privilégiées sur la conception des produits et, par conséquent, a un avantage compétitif sur le marché du remanufacturing où il compétitionne avec des remanufacturiers indépendants. Cet article étudie l'incitatif qu'ont les firmes d'accroître le niveau de remanufacturabilité lorsque, d'un côté, elles ont l'opportunité de réduire les coûts de production et, de l'autre, elles attirent de nouveaux compétiteurs. Le résultat principal indique qu'un planificateur social voulant promouvoir les activités de remanufacturing sans intervenir pourrait encourager la collusion entre les manufacturiers originaux. Cependant, si une réglementation environnementale est prévue, le planificateur social devrait alors réprimer la collusion sur le niveau de remanufacturabilité. En effet, les firmes en non-coopération verront une plus grande augmentation ou une plus petite réduction de leur profit suite à la réglementation et, conséquemment, offriront un plus grand support à l'intervention gouvernementale. Dans les deux cas, collusion et non-coopération, les résultats corroborent l'hypothèse de Porter stipulant qu'une réglementation environnementale peut accroître les profits dans l'industrie.

Durant mon investigation de la littérature (non-économique) sur le remanufacturing, je suis tombée sur l'idée bien répandue que le remanufacturing était bon non seulement pour l'environnement, mais aussi pour l'économie [Steinhilper 1998, Giutini 2003]. Plus particulièrement, certains auteurs avancent qu'en raison de l'intensité en main-d'œuvre et des marchés cibles à faibles revenus, le remanufacturing devrait être bénéfique pour les pays en développement. Dans cette ligne de pensée, Clerides (2008) montre comment la libéralisation au commerce de l'île de Chypre pour l'importation de voitures japonaises seconde-main a amélioré le bien-être. Cependant, la réalité n'est pas toujours si rose. Le mouvement de produits seconde-main de pays développés vers des pays moins développés amène son lot de problèmes : l'exportation de machineries obsolètes entretient le retard technologique des pays pauvres, le don de vêtements usagés détruit l'industrie locale du textile, alors que l'expédition de véhicules consommant beaucoup d'énergie peut devenir un coût net à long terme [Janischweski et al. 2003, Frazer 2008]. Le problème au cœur du second chapitre de cette thèse est le mouvement des biens de seconde-main qui ouvre la porte à l'expédition des déchets, faisant des pays pauvres le dépotoir des pays riches [Janischweski et al 2003, EEA 2009].

Le mouvement transfrontalier des déchets est principalement réglementé en Europe. Sous ces réglementations, l'exportation de déchets toxiques, de déchets électroniques et de véhicules usagés des pays de l'OCDE vers les pays hors de l'OCDE est interdite. Cependant, sous les conventions internationales, la définition des termes déchets, produits de seconde-main et produits recyclables ou remanufacturables reste vague, ce qui permet à des déchets non-réutilisables d'être classés comme des biens de seconde-main. Une fois classés comme tel, les produits ne sont plus régis par les réglementations internationales et peuvent dès lors être échangés avec les pays en développement.

Les gouvernements ont récemment introduit un nouveau type de réglementations, appelées responsabilité élargie des producteurs, qui attribuent aux firmes et aux producteurs la responsabilité des coûts du traitement des déchets. La directive européenne sur les déchets d'équipements électriques et électroniques (DEEE) introduite en 2005 en est un exemple. En prenant l'exemple de la France, les producteurs de DEEE sont aujourd'hui regroupés dans quatre centres de recyclage agréés. Les producteurs les plus importants sont non seulement clients, mais aussi propriétaires ou actionnaires de ces centres responsables du tri des déchets.

Dans le but de minimiser le coût de respecter ces nouvelles réglementations, les firmes considèrent l'expédition des déchets à l'étranger. La différence entre les coûts de traitement et de gestion des déchets explique le mouvement transfrontalier. Les pays hors de l'OCDE ont souvent des systèmes peu coûteux et inadéquats où les déchets électroniques finissent incinérés à ciel ouvert, une pratique dangereuse pour la santé et l'environnement [EEA 2009]. On estime que de 4 à 5 millions de tonnes de déchets électroniques ont été exportés illégalement de l'Europe en 2008 [EEA 2009].

Dans ce deuxième chapitre est développé un modèle Nord-Sud de commerce où des produits de seconde-main sont vendus à des firmes du Sud comme intrant à la production. Le manque de vigilance internationale permet à certains déchets d'être classifiés et échangés comme des biens de seconde-main. Le modèle étudie les impacts de la responsabilité élargie des producteurs et montre comment les différences de coût du traitement des déchets entre les pays constituent un facteur déterminant dans l'expédition des déchets. Ce résultat est en ligne avec l'hypothèse du paradis des pollueurs, stipulant que l'écart entre les réglementations environnementales des pays riches et pauvres amène la délocalisation de la pollution vers les pays moins développés. Cet article explore aussi l'impact d'une amélioration de la vigilance internationale. Au meilleur de ma connaissance, cet article est la première analyse théorique incorporant le mouvement illégal des déchets et des biens de seconde-main.

En parlant de petits commerces de ferraille et de l'importation illégale de déchets toxiques en Inde, Yardley, un reporteur du New York Times, écrit :

> « Critics say that the [Indian] government has been reluctant to toughen [...] monitoring because the imported waste business employs large numbers of workers and helps the country meet its demand for steel.» [Yardley, April 23, 2010]

Le phénomène ici relaté, qui prend place dans le contexte de l'expédition illégale des déchets, montre comment l'ouverture au commerce est intimement liée avec les déterminants des réglementations environnementales. Ceci décrit bien les dimensions politiques et économiques développées dans le troisième chapitre de cette thèse, *La démocratie est-elle bénéfique pour l'environnement ? Le rôle de la protection privée*, co-écrit avec Louis Hotte et Stanley L. Winer. Dans un cadre théorique, l'hypothèse est formulée qu'à travers la protection privée contre les conséquences de la pollution (par exemple, un purificateur d'air), l'inégalité du revenu amène la divergence des préférences sur deux dimensions politiques : une réglementation environnementale et l'ouverture au commerce. La façon dont chaque dimension interfère avec l'autre est semblable à la situation intuitive décrite dans la citation ci-haut. Une arène politique est ensuite construite où différents régimes politiques (de la démocratie au régime totalitaire) ainsi que le pouvoir respectif des riches et des pauvres dans chaque dimension politique amènent des résultats contre-intuitifs.

Il est bien documenté que les pauvres, plus que les riches, ont tendance à souffrir des conséquences de la pollution. Dans les économies de ce modèle, la présence de cette inégalité est expliquée par l'existence de protections privées contre la pollution, disponibles à un coût. L'eau en bouteille, les systèmes de filtration d'eau, les purificateurs d'air, la localisation des maisons, les destinations vacances ou les médicaments sont tous des exemples de telles mesures. L'existence de ces mesures pour se défendre contre la pollution a été rapportée dans la littérature,[2] mais n'a jamais été considérée comme un facteur endogène dans l'étude des déterminants des réglementations environnementales.

Les protections privées sont un facteur clé expliquant l'étendue avec laquelle les élites ou les citoyens rechercheront l'intervention du gouvernement afin de gérer la dégradation de l'environnement. Dans ce modèle, les individus diffèrent par rapport à leur niveau de revenu et, conséquemment, diffèrent par rapport à leur consommation de protection privée. Ceci influencera la proportion des actions privées et publiques émergeant aux équilibres politiques. Alors que les citoyens les plus riches préfèrent l'utilisation des protections privées ainsi que le revenu supplémentaire provenant d'une économie ouverte et peu réglementée, les plus pauvres peuvent préférer l'intervention publique et la restriction au commerce dans le but de réduire leur exposition à la pollution.

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[2] Eriksson et Persson (2003), Hotte et Winer (2008).

Les équilibres de quatre régimes politiques sont analysés où deux politiques, une réglementation environnementale et un tarif, sont déterminées. Le premier est le régime totalitaire où le résultat est déterminé par l'utilité des riches uniquement. Le deuxième équilibre est un régime démocratique où est considérée l'utilité des riches et des pauvres. En utilisant les théorèmes de la probabilité de voter (probabilistic voting theorem) et de la représentation, l'équilibre est obtenu à travers une fonction objective qui s'apparente à une fonction d'utilité sociale où les riches et les pauvres auraient différents poids. Les troisième et quatrième régimes développent les cas subordonnés inspirés par Rodrick (1992), modélisés comme des équilibres de Nash en jeux simultanés. Dans ces scénarios, les élites contrôlent une dimension politique alors que la population détient le pouvoir sur l'autre.

Dans une économie simulée, les résultats montrent que les gouvernements subordonnés peuvent performer mieux, d'un point de vue environnemental, que la démocratie. Par exemple, lorsque les riches contrôlent la dimension d'ouverture au commerce, ils choisiront un tarif plus petit que celui sélectionné en démocratie. Le gouvernement subordonné compensera alors en optant pour une réglementation environnementale plus stricte que le scénario démocratique. Il est aussi démontré que lorsque les riches ont un poids plus important dans un régime démocratique, les régimes subordonnés ont plus de chance d'être moins polluants.

General introduction

Three chapters constitute my doctoral dissertation. They are divided in two distinct subjects on environmental economics. The first two chapters, titled *Remanufacturing* and *Transboundary Movements of Waste*, explore what occurs to products at the end of their life. They incorporate the study of regulations promoting green designs that improve waste and product reuse. The third chapter, titled *Is democracy good for the environment? The Role of Private Mitigation Efforts*, explores the environment-trade-democracy nexus.

The first two papers study waste reuse. This activity is environmentally desirable because it reduces not only post-consumption waste, but also the use of raw materials. In addition to these environmental benefits, waste reuse gives the opportunity to satisfy the consumption needs of a larger share of the population. Second-hand products, differentiated from the original ones in terms of quality or technological generation, are more accessible for lower-income individuals. Product differentiation comes with market segmentation and plays a crucial role in the competitive environment where original producers and recyclers evolve.

Competition is the theme of my first chapter, *Remanufacturing*. Remanufacturing is a type of recycling where products are refurbished to a like-new condition. The particularity of this market relies on the fact that products, at the end of their useful life, can be remanufactured with reduced production cost and sold again. Typically, products are remanufactured at 35 to 60 percent of the original cost and sold at 60 to 70 percent of the new product's price [Giuntini and Gaudette 2003]. This profit possibility attracts not only original producers on the secondary market, but also independent remanufacturers. This characteristic is not exclusive to the remanufacturing industry and has been observed in the market of raw material recycling. For instance, aluminum producers are voluntarily involved in the recycling industry because "aluminum is so valuable and so easy to recycle" [www.alcoa.com].

The process of remanufacturing is both an engineering and a management challenge since not only products must be designed in order to serve the cleaning, opening, replacing parts and refurbishing processes, but they also must find their way back to remanufacturers after consumption. Hence, remanufacturing has been a hot topic in the engineering and managerial worlds, witness the flourishing literature on reverse logistic, stock planning, material demand and return, and case studies.[3] Nonetheless, this 60-100 billion dollar industry is almost absent from the economic literature and only a few studies consider the effect of public interventions on remanufacturing [Webster and Mitra 2007; Mitra and Webster 2008]. After a close examination of the American market, Lund explains that because of the variety of products and the small size of actors, this industry remains "virtually invisible" to decision makers. Consequently, remanufacturing activities stay vaguely defined, under-estimated and under-regulated [Lund 1984, Hauser and Lund 2003].

This first chapter is inspired from the alternator industry, where an asbestos ban has rendered alternators remanufacturing economically viable. When looking at the history of alternator production, the implementation of the regulation on asbestos and remanufactur-

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[3] See for instance Ferrer (1997), Kiesmuller and Laan (2001), Majumder and Groenevelt (2001), Lebreton and Tuma (2006), Ferrer and Swaminathan (2006), Chung and We (2008).

ing activities in this industry, a legitimate question is: If remanufacturing is so profitable today, why didn't alternator manufacturers voluntarily remove asbestos from their production? In the attempt to answer this question, I had access to privileged informations through personal contacts from the industry.

The industry is modeled as follows. A duopoly of original producers holds privileged information on product conception and, therefore, has a competitive advantage on the remanufacturing market where it competes with independent remanufacturers. This paper studies firms' incentives to increase the level of remanufacturability of their products when, on one hand, they have the opportunity to save on production costs and, on the other hand, they attract new competitors. The main result indicates that a social planner who wants to promote remanufacturing activities without direct intervention should encourage collusion between original manufacturers. However, if an environmental regulation is scheduled, the social planner should repress collusion on the level of remanufacturability. Indeed, non-cooperative firms see a larger increase or a lower reduction in their profit due to the regulation and, in turn, support the intervention better. For both cases of collusion and non-cooperation, the impact of an environmental regulation corroborates the Porter Hypothesis, which says that an environmental regulation may increase the profits of regulated industries.

While investigating the (non-economic) literature on remanufacturing, I came across the widespread idea that remanufacturing is good not only for the environment, but also for the economy [Steinhilper 1998, Giutini 2003]. More particularly, some authors argue that because remanufacturing is a labor-intensive industry and because remanufactured products fit low-income markets better, remanufacturing should benefit developing countries. In this line of thought, Clerides (2008) shows how trade liberalization in Cyprus for the import of second-hand Japanese automobiles was welfare improving. However, the reality is not always that pretty. The movement of second-hand products from developed to less developed countries brings its load of problems: the export of old machinery may keep the technology lag between rich and poor countries, used cloth donations destroy local textile industries, and the shipment of old energy inefficient vehicles may be more of a cost than a benefit in the long run [Janischweski et al. 2003, Frazer 2008]. The problem at the heart of the second chapter is that the movement of second-hand goods opens the door to the shipment of waste, making poor countries the rich's landfill [Janischweski et al. 2003, EEA 2009].

Transboundary movements of waste are mostly regulated in Europe, where the export of hazardous waste, e-waste and used vehicles from OECD to non-OECD countries is prohibited. However, under international conventions, the vague definition of waste, second-hand goods, recyclable or remanufacturable products causes waste to be misclassified as second-hand products. When products are classified as second-hand goods, they are no longer governed by international waste regulations and can be traded with developing countries.

Governments have recently introduced new types of regulations by making firms and producers responsible for waste disposal cost. The European Union's Directive on Waste Electrical and Electronic Equipment (WEEE) introduced in 2005 is an example. These regulations are called extended producer responsibility. Taking the example of France, WEEE producers are gathered today in four recycling centers recognized by the government. The most important producers are not only clients, but also owners or stockholders of these recycling centers, which are responsible for sorting activities.

In order to minimize the cost of complying with new environmental regulations, firms consider shipments of waste as an alternative. The difference in the cost for treatment and disposal remains one of the driving forces for transboundary shipments. Non-OECD countries often have low-cost and inadequate facilities where e-waste often ends up incinerated in open fires, a practice which is unsafe both for the environment and human health [EEA 2009]. It is estimated that 4 to 5 millions of tons of WEEE were illegally exported from Europe in 2008 [EEA 2009].

The second chapter develops a North-South model with trade where second-hand products are sold to firms in the South as an input to production. The lack of international vigilance allows for waste to be misclassified and then traded as second-hand goods. The model studies the impact of extended producer responsibility programs and shows how the difference in waste disposal cost between the two countries is a key determinant in explaining shipments of waste. The results are in line with the Pollution Haven Hypothesis, which says that the gap between environmental regulations in the North and the South leads to a delocalization of pollution towards less developed countries. This article also explores the impact of better enforcement in international vigilance. To the best of my knowledge, this is the first theoretical analysis of the transboundary movement of illegal waste and second-hand products.

Talking about scrap metal shops and the illegal import of toxic waste in India, Yardley, a New York Times reporter, writes:

> "Critics say that the [Indian] government has been reluctant to toughen [...] monitoring because the imported waste business employs large numbers of workers and helps the country meet its demand for steel." [Yardley, April 23, 2010]

The phenomenon related here, which takes place in the context of illegal shipments of waste, shows how the choice of trade openness is intimately bound up with the determinant of environmental regulations. It describes well the political and economic dimensions developed in the third chapter, titled *Is democracy good for the environment? The Role of Private Mitigation Efforts*, coauthored with Louis Hotte and Stanley L. Winer. In a theoretical framework, the assumption is made that through private mitigation against pollution (for instance, air purifiers), income inequality leads to divergence of preferences over two policy dimensions: environmental regulation and openness to trade. The way each policy dimension interferes with the other is similar to the intuitive situation described in the quote above. A political arena is then constructed where the different political regimes (from democratic to totalitarian), as well as the respective power of rich and poor in each policy dimension, can bring counter-intuitive results.

It is well documented that people are not equally affected by pollution. Poor people tend to suffer more from the adverse consequences of pollution. In the economies analytically constructed, the presence of this inequality is explained by the existence of private mitigation against pollution, available at a cost. Bottled water, water filtration system, air purifier, house location, vacation or medicines are examples of such private measures. The existence of such measures to defend ourselves against local pollution has often been noted in the literature,[4] but has never been considered an endogenous factor in the study of the determinants of environmental regulation.

Private mitigation is key to determining the extent to which elites or citizens seek government regulation to deal with environmental degradation. Because in our model individuals differ with respect to the level of income, they express different willingness to pay for private mitigation services and, in turn, influence the balance between public and private action and the equilibrium policy mix. While richer citizens prefer the use of private defence against pollution and the higher income that comes with an open and unregulated economy, poorer individuals may prefer public interventions and restriction to trade in order to reduce their exposure.

The equilibria of four political regimes are analyzed where the two policies, environmental regulation and tariff, are determined. The first one is a totalitarian regime where the outcome is determined by the rich individuals only. The second equilibrium is a fully democratic regime where the utility of both the rich and the poor citizens is considered. Using the probabilistic voting and the representation theorems, the equilibrium is obtained through an objective function similar to a social utility function where rich and poor have different weights. The third and fourth regimes develop subordinate cases inspired from Rodrick (1992), modeled as Nash equilibria in simultaneous games. In these scenarios, the elite control the one policy dimension and the population lead on the other.

Under a simulated economy, results show that subordinate governments may be more eco-friendly than a fully democratic regime. For instance, when the rich control the trade

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[4] Eriksson and Persson (2003), Hotte and Winer (2008).

openness dimension, they will choose a tariff lower than what would be selected in a democracy. The subordinate government compensates by opting for a higher environmental regulation than the democratic scenario. It is also shown that when the rich are more weighted in a democracy, subordinate regimes are more likely to be less polluting.

Chapter 1
Remanufacturing

1.1 Introduction

Remanufacturing is a specific type of recycling in which used durable goods are repaired to a like-new condition. Both remanufacturing and recycling avoid post-consumption waste while reducing the use of raw materials. However, recycling is an energy-intensive process that conserves only material value. In attempting to meet multiple environmental objectives, remanufacturing can be a more suitable option; it preserves most of the added-value by giving a second life to the product and, typically, reduces the use of energy by eliminating production steps.

Recycling or remanufacturing-oriented designs generally raise initial production costs. Because the environmental benefits of such designs are not totally internalized, choices of production technology are suboptimal. Authors propose different public interventions for optimal recyclable technology. Take-back regulations, consumption and production taxes, subsidies to green designs as well as subsidies to the demand for recyclable material input create strong incentives for the development of recyclable goods [Fullerton and Wu 1998; Eichner and Pethig 2001; Eichner and Runkel 2005; Toffel *et al.* 2008]. This has lead governments to introduce recycling-oriented regulations. The European Union's Directive on Waste Electrical and Electronic Equipment in 2005 is an example of take-back regulation. The European Union's End of Life Vehicle Directive introduced in 2006 stipulates that every new vehicle must have recyclable contents of 85 percent (95 percent by 2015). In the United States, goods purchased by federal agencies must respect the Electronic Product Environmental Assessment Tool issued in 2007 that regulates product design and requires products to have a reusable or recyclable content of 65 percent.[5]

Although existing governmental regulations are not specifically directed towards remanufacturing, it seems that similarities between recycling and remanufacturing are such that their corresponding public interventions use comparable mechanics. Webster and Mitra (2007) and Mitra and Webster (2008) have pointed out that take-back regulations as well as subsidies can encourage remanufacturing activities. Furthermore, because recyclable and remanufacturable products present common characteristics in their conception [Steinhilper 1998], regulations aimed at either recycling or remanufacturing may interchangeably foster one activity or the other.

After a product's first life, recycled material can be redirected towards any industry. On the contrary, the material going through the remanufacturing process goes back to the same industry. Then, remanufacturing-oriented designs permit the *original manufacturers* (OMs) to access the aftermarket's benefits. Indeed, while remanufactured products are sold at 60 to 70 percent of the new products' price, their production accounts for only 35 to 60 percent of the original costs [Giuntini and Gaudette 2003]. Therefore, when new products can be substituted with remanufactured ones, original manufacturers may undertake profitable remanufacturing initiatives. Xerox, Kodak, Ford Motor Company and Mercedes-Benz are examples of corporations that could reduce their production costs with

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[5] For more details on the different regulations see Toffel *et al.* (2008).

voluntary product recovery [Toffel 2004]; and they are part today of a 60-100 billion dollar industry according to the sources. Over the years, profitability concerns have made remanufacturing a hot topic in the engineering and managerial worlds, witness the flourishing literature on reverse logistic, stock planning, material demand and return, and case studies.[6] Nonetheless, there are only a handful of economic studies that consider the effect of public interventions on remanufacturing [Webster and Mitra 2007; Mitra and Webster 2008].

In this framework, the car parts industry is of particular interest. Combined, alternators and starters represent 80 percent of remanufactured products [Kim *et al.* 2008]. Valeo and Bosch are two important alternator producers in Europe. They started remanufacturing activities in the early 90's, following the announcement of legislation prohibiting the production, sale and use of asbestos:[7] a technological constraint that has made alternator remanufacturing commercially viable.

A study by Debo *et al.* (2005) analyzes the technology selection for remanufacturable goods when a higher remanufacturability may invite entry by *independent remanufacturers* (IRs).[8] Stronger competition on the remanufacturing market pulls down prices and OMs show lower interest in costly production technology. Therefore, governmental interventions promoting competition on the aftermarket negatively influence the level of remanufactura-

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[6] See for instance Ferrer (1997), Kiesmuller and Laan (2001), Majumder and Groenevelt (2001), Lebreton and Tuma (2006), Ferrer and Swaminathan (2006), Chung and We (2008).

[7] This legislation was enacted in 1993 in Germany and in 1997 in France, the respective headquarters of Bosch and Valeo, with the European Union following suit in 1999 [European Commission 1999].

[8] Since remanufacturability gives the products a positive value at the end of their life, OMs have the incentive to offer remanufacturable products when the end of life value is reflected in the original product price.

bility. This corroborates the observation of Ferrer (2000) who says that remanufacturing is viable only if the remanufactured product is priced above its marginal cost.

Studies that observe effects of competition on the remanufacturing market generally omit to discuss the implication of competition on the primary market where they assume a monopolistic original manufacturer.[9] The current paper proposes a theoretical model of remanufacturing inspired by Debo *et al.* (2005) and framed on the particularities that characterize the alternator industry. A duopoly of OMs compete on the primary market where they face the threat of an outsider; they also compete on the aftermarket where consumers of remanufactured products may alternatively use the services of competitive IRs. The model pins down the different incentives in the technology selection determining the level of remanufacturability and explores the consequences of environmental regulations. Particularly, it explains why original alternator manufacturers refrained from adopting a voluntary withdrawal of asbestos from their production in order to launch profitable remanufacturing activities.

The main results show that in the absence of environmental regulation, collusion leads to a higher level of remanufacturability as well as higher profits in the industry. However, the introduction of environmental regulations imposing a minimum level of remanufacturability can be beneficial to firms. In the absence of public intervention, the threat of entry on the primary market imposes support for all the costs of remanufacturing-oriented technologies on the OMs, while environmental benefits are shared by all. Consequently,

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[9] See for instance Mitra and Webster (2008), Debo *et al.* (2005) and Majumder and Groenevelt (2001). In a different context, Heese *et al.* (2005) study a duopoly that compete on the primary market. In their model, new products have a positive initial remanufacturability level. Hence the first mover in launching take-back strategy can deter the competitor by offering a new product with a lower price that includes a discount for the consumer who will return the used product.

OMs can gain additional profits when the regulation justifies a raise in the original product price that covers the cost of remanufacturability. This result is in line with the Porter Hypothesis stating that environmental regulations may increase profits in regulated industries.

The model is introduced in the next section, which sets technologies, demands and the industrial structure. Section 1.3 completes the assumption on technology and describes the optimization problem for two cases: non-cooperation and collusion. Section 1.4 observes the effect of an environmental regulation. Section 2.5 concludes.

1.2 The Model

A duopoly[10] of identical original manufacturers (OMs) produce an intermediate good m (the alternator), which enters as a component of a final consumption good (the vehicle). This constitutes the primary market and the component's first life. Since the same car goes through two or three alternators [Kim *et al.* 2008], the lifetimes of the alternator and the vehicle are respectively l and L, with $l < L$. Consequently, consumers of the final good have to replace the specific component b times, where $b = (L/l) - 1$. This creates an aftermarket.

The alternator's original life aims specifically at the new vehicle industry with one alternator per vehicle. Used alternators can be remanufactured several times and, at any moment, there are an equal number of cars and alternators on the market.

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[10] A duopoly is assumed for simplicity.

When they originally produce a remanufacturable component, OMs participate in the aftermarket by recovering and remanufacturing used products. On this market, however, they face competition from independent remanufacturers (IRs).

1.2.1 Technology and pollution

OMs control their level of remanufacturability q_i, $i \in \{1,2\}$, a technology choice corresponding to the ease with which a used product can be remanufactured[11] and leading to decreasing unit remanufacturing costs $c_r(q_i)$ and $c_s(q_i)$, for OMs and IRs respectively. However, IRs hold only partial information on the original product conception and hence, for any given q, they meet larger remanufacturing costs than OMs. This *technological advantage* for OMs over the IRs is represented by the following properties:

$$c_s(q) - c_r(q) \geq 0; \text{ and asymptotically: } \lim_{q_i \to \infty} c_s(q) = \lim_{q_i \to \infty} c_r(q) = 0. \tag{1.1}$$

To make the original product more remanufacturable, OMs bear additional production costs reflected by an increasing and non-concave initial manufacturing cost, $c_m(q_i)$.

The remanufacturing cost reduction associated with a larger level of remanufacturability is mostly due to a reduction in energy and raw material consumption; hence it is environmentally desirable. In particular, Steinhilper (1998) shows that on average remanufactured alternators and starters require 14% of the energy and 12% of the material necessary for the production of new ones. Furthermore, lower remanufacturing costs for the OMs

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[11] In most models [see for instance Debo *et al.* 2005; Majumder and Groenevelt 2001; Ferrer and Swaminathan 2006] the level of remanufacturability is the percentage of returned and/or remanufacturable used products. While the share of un-remanufacturable cores can exceed 30% for certain products, it is less than 15% for alternators [Kim *et al.* 2008]. In the present model, this number is assumed to be negligible so that the alternator/vehicle ratio stays equal to 1.

(equation (1.1)) can denote better use of material and energy. Therefore a social planner showing environmental concerns may manifest a preference for products remanufactured by OMs.

1.2.2 Demand functions

The demand for the component is segmented into two types: the demands for new and for remanufactured products.

The demand for new products m is driven by the final good producers. It is assumed that any variation in the original component price represents a small share of the final good production cost and, hence, the demand for m stays inelastic for a reasonably large range of prices (or until a certain choke price). Except for great demand elasticities, this assumption does not affect the results, but lightens the model. For simplicity, m is normalized to 1.

The demand for remanufactured products comes from consumers who need to replace the defective part at each of the b replacement periods. Consumer types are uniformly distributed over $\theta \in [0, 1]$, where θ is the marginal willingness to pay for quality. When remanufacturing used products, OMs provide the properties and warranty of new goods while IRs supply products of lower quality. As a result, consumers will express lower willingness to pay for IRs' products. The parameter $\delta \in [0, 1]$ reflects this perceived depreciation in quality.

At each replacement period, individuals maximize their consumer surplus by purchasing a product coming from an OM, an IR or no product at all. This maximization problem is given by: $\max[\theta + \alpha - p_r, (1-\delta)\theta + \alpha - p_s, 0]$, where p_r and p_s are respectively

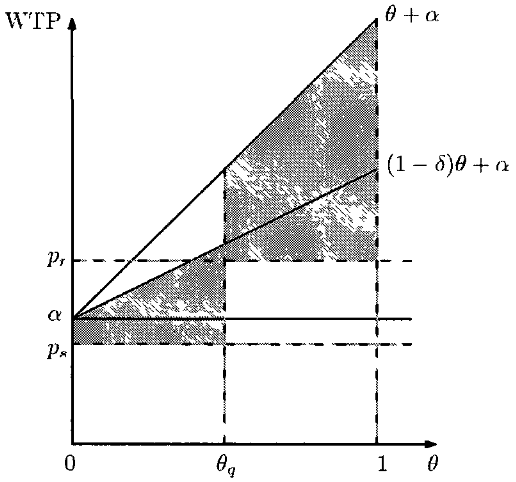

Fig. 1.1. Willingness to pay and consumer surplus

the selling price of OMs and IRs' products. The positive constant α indicates that even individuals from the lower bound are willing to pay a positive amount. Because the component price represents a small fraction of the final good's value, $\alpha \geq p_s$ mimics the inelastic aftermarket and ensures that everyone consumes a replacement good; that is, $r + s = 1$, where variables r and s designate the demand for components remanufactured by the OMs and the IRs respectively. Figure 1.1 illustrates the willingness to pay for the two differentiated products.

The set of consumers buying remanufactured products from the OMs is defined by θ such that $\theta + \alpha - p_r \geq (1-\delta)\theta + \alpha - p_s$, or equivalently: $\theta \geq (p_r - p_s)/\delta$. In Figure 1.1, given prices p_r and p_s, individual θ_q is indifferent between the two products. Types $\theta \in [\theta_q, 1]$ prefer OMs' services while the others, $\theta \in [0, \theta_q]$, purchase lower quality goods. The shaded area corresponds to the total consumer surplus at each replacement period.

Given a uniform distribution for θ, the demand for products remanufactured by the OMs at each period is $r = 1 - (\frac{p_r - p_s}{\delta})$ so that the inverse demand function is:

$$p_r = \delta(1 - r) + p_s. \tag{1.2}$$

For any positive value of the parameter δ, this depicts the remanufactured alternator industry where the observed OMs' prices are from 25 to 200 percent higher than their competitors' [Kim *et al.* 2008]. This premium adds an incentive to the OMs that stays unexplored in the literature.

1.2.3 Industrial structure

Competition in the industry is described by the following four-stage game. In the first stage, two identical OMs produce the original component and control its level of remanufacturability $q_\imath$. Two different competitive environments will be considered in determining $q_\imath$: non-cooperation and collusion. These scenarios internalize, or not, the fact that firms can free-ride on each other's technology selection $q_\imath$.

In the second stage, OMs set the original product's prices and quantities $p_{m\imath}$ and $m_\imath$. They face the threat of an outsider that would seize any profit opportunities originating from the original market but who stays blind on what occurs on the remanufacturing market.[12] This threat forces price competition between OMs, reflecting the automotive industry: original components being perfectly substitutable, vehicle manufacturers can switch from one supplier to the other as soon as a lower price is offered.

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[12] Two arguments are proposed in order to explain this behaviour. The first one assumes that reputation is an important factor in being considered as an OM and, therefore, new entrants cannot benefit from a price premium on the aftermarket. The second point considers that incumbents face less risk and are more willing to accept delayed profits.

The third and fourth stages occur on the aftermarket. Although this market is shared with IRs, OMs hold an oligopolistic power on high quality products. In the third stage, OMs compete by choosing quantities r_i. In the final stage, IRs compete perfectly and their remanufactured good's price is established.

Because of the inelastic aftermarket size, it is assumed that OMs and IRs cannot discriminate between products that have different levels of remanufacturability (everything has to be remanufactured).

OMs have perfect knowledge of each other. Their decisions in each stage are made and applied simultaneously. They also have perfect information about IRs' characteristics. Since OMs are identical, a symmetric subgame-perfect equilibrium in pure strategies in the four-stage game is computed.

1.3 The optimization problem

Under the market clearing conditions, $m_1 + m_2 = 1$ and $r_1 + r_2 = r$. The OMs' profit function depends on both their activities on the primary market and the remanufacturing market:

$$\pi_i = (p_{mi} - c_m(q_i))m_i + \underbrace{\sum_{t=1}^{b} \beta_l^t [(p_r - m_i c_r(q_i) - m_j c_r(q_j)) r_i]}_{R_i(r_i, r_j, m_i, m_j, q_i, q_j)} \text{ for } i = 1, 2 \text{ and } j \neq i$$

where $p_r = \delta(1 - r) + p_s$ from equation (1.2) and $0 < \beta_l < 1$ is the discount factor associated with the length of time l. The first term is the net profit from the original market while $R_i(r_i, r_j, m_i, m_j, q_i, q_j)$ corresponds to the discounted profit from all the remanufacturing periods. Because used products randomly go to any remanufacturer, the remanufacturing cost depends on the technology selection of each OM and is weighed by their respective participation in the original market.

1.3.1 Prices and quantities

Using backward induction, the final stage is solved first. IRs are perfectly competitive and the selling price p_s is set at the average unit cost of remanufacturing:

$$p_s = m_i c_s(q_i) + m_j c_s(q_j). \tag{1.3}$$

In the third stage, OM i maximizes its profit on the aftermarket by choosing its supply of remanufactured products r_i, and by taking the supply choice of its opponents r_j as well as the levels of remanufacturability (q_i, q_j) as given. It also considers IRs' behavior through equation (1.3). The OMs maximization problem at this stage is:

$$\begin{aligned} \max_{r_i \geq 0} R_i &= \sum_{t=1}^{b} \beta_l^t [(\delta(1-(r_i+r_j)) + m_i(c_s(q_i) - c_r(q_i)) + m_j(c_s(q_j) - c_r(q_j)))r_i] \\ & \quad \text{for } i = 1,2 \text{ and } j \neq i \end{aligned}$$

and the first-order condition is:

$$\frac{\partial R_i}{\partial r_i} = 0 \Longleftrightarrow \sum_{t=1}^{b} \beta_l^t [\delta - \delta r_j - 2\delta r_i + m_i(c_s(q_i) - c_r(q_i)) + m_j(c_s(q_j) - c_r(q_j))] = 0. \tag{1.4}$$

The Nash equilibrium for the supply of remanufactured products is defined by:

$$r_i^*(m_i, m_j, q_i, q_j) = \frac{\delta + m_i(c_s(q_i) - c_r(q_i)) + m_j(c_s(q_j) - c_r(q_j))}{3\delta} \text{ for } i = 1,2 \text{ and } j \neq i \tag{1.5}$$

and the second-order condition for an interior maximum is respected when evaluated at r_i^*.

Here, IRs play a passive role since their price is driven by the OMs' choice of remanufacturability (equation 1.3). Also, they only have a residual participation in the aftermarket;

the demand for their products depends on OMs' supply decisions with $s^* = 1 - 2r_i^*$. Note that the choice of $2r_i^*$ also corresponds to OMs' aftermarket share.

In the second stage, the two OMs compete on the primary market where free-entry of the outsider keeps the component price p_{mi} at the minimum production cost; that is,

$$p_{m1} = p_{m2} = c_m(0). \tag{1.6}$$

By offering a common original price, OMs share this market equally with $m_i = 1/2$. If a higher price is set, the outsider, by proposing the lowest level of remanufacturability, can make a strictly positive profit and deter competitors. Note that in spite of that restriction, OMs may still optimally choose a positive level of remanufacturability and, consequently, bear deficit on the primary market ($p_{mi} - c_m(q_i) = c_m(0) - c_m(q_i) \leq 0$).

Two situations are considered for the determination of q_i and q_j in the first stage. The first case reflects the non-cooperative problem that occurs when an OM remanufactures used products from random origin and free-ride on the technology selection of the other. The second case considers the possibility of an agreement between the OMs. These situations are explicitly formulated in subsections 1.3.3 and 1.3.4.

Before solving for the choice of remanufacturability, an important assumption on the technology selection is introduced in the coming subsection.

1.3.2 Assumption on the technology selection

At this step, only the first stage equilibrium remains to be solved and everything thereafter depends on the technology selection (q_i, q_j) taken as given. The profit function is:

$$\pi_i^* = (c_m(0) - c_m(q_i))\frac{1}{2} + \underbrace{\sum_{t=1}^{b} \beta_l^t [\delta r_i^*(q_i, q_j)^2]}_{R_i(q_i,q_j)}. \tag{1.7}$$

where the optimal supply of remanufactured products (equation (1.5)) is reduced to:

$$r_i^*(q_i, q_j) = \frac{\delta + c_s(q_i) - c_r(q_i)}{6\delta} + \frac{\delta + c_s(q_j) - c_r(q_j)}{6\delta} \tag{1.8}$$

when the individual market share in equilibrium, $m_i = 1/2$, is taken into account.

A variation in q affects the profit through two channels: i) the original production cost $c_m(q_i)$; and ii) the total net revenue of remanufacturing activities $R_i(q_i, q_j)$. Since OMs are identical, the analysis will focus on symmetric equilibria $q_i = q_j = q$. OMs know that, for any given q, their profit depends substantially on their technological advantage: $c_s(q) - c_r(q)$. The comparative static

$$\frac{\partial r_i^*}{\partial q} = \frac{c_s'(q) - c_r'(q)}{3\delta} \tag{1.9}$$

indicates that, with an increasing technological advantage, a higher level of remanufacturability leads to a larger aftermarket share and, consequently, higher remanufacturing revenues.

The following assumption completes the description of the technological advantage introduced in section 1.2.1. It is assumed that for small levels of remanufacturability, OMs have access to a wide choice of different technologies and they shape the original product

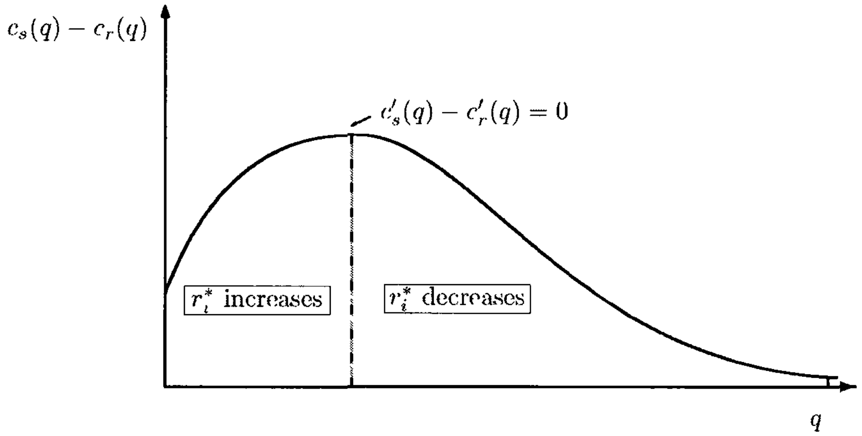

Fig. 1.2. Technological advantage

in order to suit their own facilities or assembly lines. Consequently, for small enough q, OMs pick a technology for which their unit remanufacturing cost decreases more than their competitors';[13] that is: $c'_s(q) - c'_r(q) > 0$. As the level of remanufacturability goes higher, the range of technology choices lessens and $c'_s(q) - c'_r(q)$ decreases until IRs get the edge with $c'_s(q) - c'_r(q) \leq 0$. This situation occurs for instance when a larger q eliminates disassembly or reassembly steps that were originally costlier for IRs.[14] Formally, with $\widehat{q} < \widetilde{q}$, the technological advantage is described by equation (1.1) and:

$$c'_s(q) - c'_r(q) \begin{cases} > 0 \text{ for } q < \widehat{q} \\ = 0 \text{ for } q = \widehat{q} \\ \leq 0 \text{ for } q > \widehat{q} \end{cases} \quad \text{and} \quad c''_s(q) - c''_r(q) \begin{cases} < 0 \text{ for } q < \widetilde{q} \\ = 0 \text{ for } q = \widetilde{q} \\ \geq 0 \text{ for } q > \widetilde{q} \end{cases} \tag{1.10}$$

Variation of the technological advantage with the level of remanufacturability is illustrated in Figure 1.2.

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[13] This may also be related to some industrial strategies. For instance, in the toner cartridge industry, some firms have added an electronic key in their remanufacturable cartridges that must be reset by the OM. This leads to an increase in the relative remanufacturing cost of IRs [Majumder and Groenevelt 2001].

[14] By the mean value theorem, $c'_s(q) - c'_r(q) \leq 0$, for at least some q, is an essential condition for the respect of equation (1.1).

1.3.3 The non-cooperative case

Each manufacturer i maximizes its profits by choosing the level of remanufacturability q_i, taking the technology choice of the other q_j as given and considering the optimal supply of remanufactured products $r_i^*(q_i, q_j)$. Used products are randomly dispatched among remanufacturers (both OMs and IRs) and, therefore, the technology selection of i is subject to free-riding. The maximization problem is:

$$\begin{aligned}
&\max_{q_i \geq 0} \pi_i^* = (c_m(0) - c_m(q_i))\frac{1}{2} + \sum_{t=1}^{b} \beta_l^t \left[\delta r_i^*(q_i, q_j)^2\right] \text{ for } i = 1, 2 \text{ and } j \neq i \\
&\text{s.t. } r_i^*(q_i, q_j) = \frac{\delta + c_s(q_i) - c_r(q_i)}{6\delta} + \frac{(\delta + c_s(q_j) - c_r(q_j))}{6\delta},
\end{aligned}$$

and the first-order condition is:

$$\begin{aligned}
\frac{\partial \pi_i^*}{\partial q_i} &= 0 \Longleftrightarrow -\frac{c_m'(q_i)}{2} + \sum_{t=1}^{b} \beta_l^t \left[\frac{2\delta(c_s'(q_i) - c_r'(q_i))}{6\delta} r_i^*(q_i, q_j)\right] = 0 \\
& \quad \text{for } i = 1, 2 \text{ and } j \neq i
\end{aligned}$$

where the marginal cost of a higher level of remanufacturability is equal to the marginal revenue generated when the choice of the other is taken as fixed. The symmetric Nash equilibrium q_{nc}^* is defined by:

$$-c_m'(q_{nc}^*) + \underbrace{\sum_{t=1}^{b} \beta_l^t \left[\frac{2(c_s'(q_{nc}^*) - c_r'(q_{nc}^*))}{3} r_i^*(q_{nc}^*)\right]}_{R'(q_{nc}^*)} = 0 \qquad (1.11)$$

where the subscript nc stands for the non-cooperative case. It is assumed that the second-order condition for an interior maximum is respected when evaluated at the symmetric equilibrium q^*_{nc}.[15] In presence of a corner solution $q^*_{nc} = 0$, the component is not remanufacturable.

A positive q^*_{nc} denotes *voluntary* remanufacturing activities in the industry.

1.3.4 When collusion on q is tolerated

In this scenario, OMs agree on a unique level of remanufacturability $q_\imath = q_\jmath = q_c$, where the subscript c refers to the collusive case. OMs internalize each other's free-riding behaviour by choosing the level of remanufacturability q^*_c that maximizes joint profit (however they still suffer from IRs' free-riding activities), which becomes:

$$\begin{aligned} &\max_{q\geq 0} \pi^*_1 + \pi^*_2 = (c_m(0) - c_m(q_c)) + 2\sum_{t=1}^{b} \beta^t_l[\delta r^*_\imath(q_c)^2] && (1.12)\\ &\text{s.t. } r^*_\imath(q_c) = \frac{\delta + c_s(q_c) - c_r(q_c)}{3\delta}. \end{aligned}$$

The first-order conditions is:

$$\frac{\partial \pi^*_\imath}{\partial q} = 0 \Longleftrightarrow -\frac{c'_m(q^*_c)}{2} + \underbrace{\sum_{t=1}^{b} \beta^t_l \left[\frac{2(c'_s(q^*_c) - c'_r(q^*_c))}{3} r^*_\imath(q^*_c)\right]}_{R'(q^*_c)} = 0 \qquad (1.13)$$

and it is assumed that the second-order condition for an interior maximum is respected when evaluated at q^*_c.[16]

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[15] The second-order condition is $-c''_m(q^*_{nc})+ R''(q^*_{nc})$. For any given q, $R''(q) = \sum_{t=1}^{b} \beta^t_l \left[\frac{2}{3}\left(\frac{(c''_s(q)-c''_r(q))}{3} r^*_\imath(q) + \frac{(c'_s(q)-c'_r(q))^2}{3\delta}\right)\right]$. From the specifications of equation (1.10), the condition is satisfied in a large neighbourhood of $q = \widehat{q}$. Note that if $c''_s(q) - c''_r(q)$ is monotonically increasing for $q < \widetilde{q}$, then when a maximum exists, it is included in the neighbourhood of $q = \widehat{q}$ and it is unique.

[16] The second-order condition is $-c''_m(q^*_c)/2+ R''(q^*_c)$. See footnote 15 for details.

Proposition 1 *Collusion on the level of remanufacturability leads to a higher level of remanufacturability, larger OMs' remanufacturing activities and higher profits:*

$$q^*_{nc} < q^*_c,\ r^*_i(q^*_{nc}) < r^*_i(q^*_c)\ \textit{and}\ \pi^*_i(q^*_{nc}) < \pi^*_i(q^*_c).$$

Proof: The optimal choice of q^*_{nc} and q^*_c are determined by equations (1.11) and (1.13). From the second-order condition, $-c''_m(q)/2 + R''(q) \leq 0$. Therefore, $q^*_{nc} < q^*_c$. Both q^*_{nc} and q^*_c are in a neighbourhood where $R'(q) > 0 \iff (c'_s(q) - c'_r(q)) > 0$. Hence, from equation (1.9), $r^*_i(q^*_{nc}) < r^*_i(q^*_c)$. Finally, $\pi^*_i(q^*_{nc}) < \pi^*_i(q^*_c)$ because the externality is internalized.

Figure 1.3 illustrates $\pi^*_i(q)$ (the lower curve) and shows $q^*_{nc} < q^*_c$ as well as $\pi^*_i(q^*_{nc}) < \pi^*_i(q^*_c)$. *Proposition 1* suggests that a government seeking environmental objectives without public intervention could tolerate industrial agreements on the level of remanufacturability as a partial substitute to environmental regulations; although this could be interpreted as a cartel strategy. These agreements could take place within manufacturers and remanufacturers associations like the international Automotive Parts Remanufacturers Association or the United States Council for Automotive Research.[17]

In this scenario however, firms' private benefits still omit the environmental benefits. Therefore public intervention remains necessary for a socially optimal technology selection.

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[17] See http://apra.org/ and www.uscar.org.

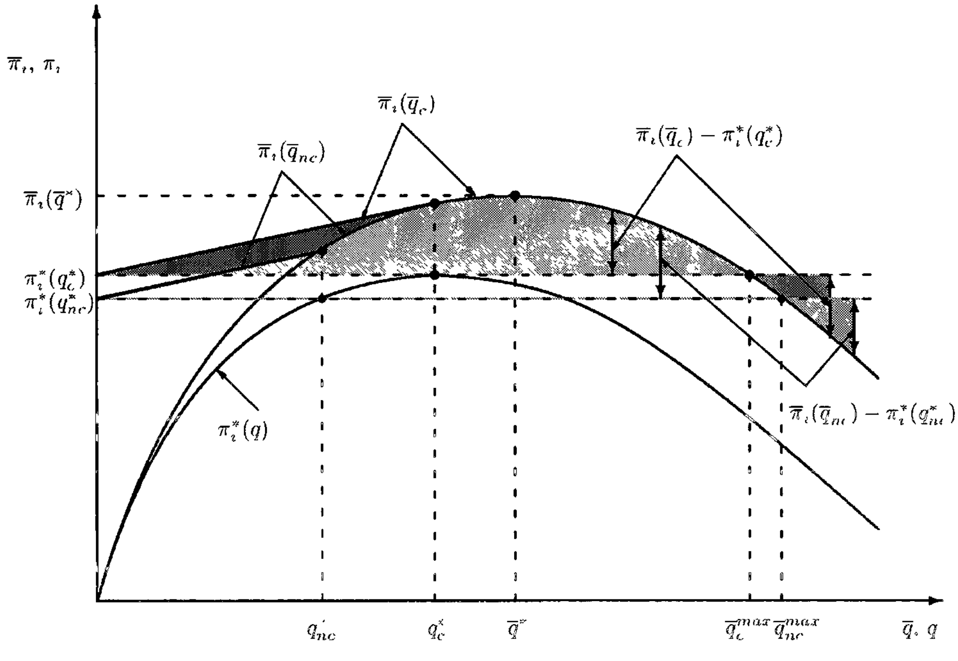

Fig. 1.3. Profit with and without regulation

1.4 Environmental regulation

In this economy, the government may decide to introduce an environmental regulation which establishes a minimum level of remanufacturability, denoted by $\overline{q}$.

Here, the objective is not to solve for the social planner's problem, but to observe how the industry would react in case of an environmental regulation. In particular, the analysis shows under which conditions the OMs go along with the regulation or resist compliance with it.

1.4.1 Public intervention

Under public intervention, the four stages stay the same but firms face a more stringent technological constraint: $q_i \geq \overline{q}$. Because this regulation applies also to the outsider, the minimum production cost increases at $c_m(\overline{q})$ and the second stage equilibrium leads to an increased original component's price:

$$p_{m1} = p_{m2} = c_m(\overline{q}).$$

Hence, the profit function becomes:

$$\overline{\pi}_i(\overline{q}_k) = (c_m(\overline{q}) - c_m(\overline{q}_k))\frac{1}{2} + \sum_{t=1}^{b} \beta_i^t \left[\delta r_i^*(\overline{q}_k)^2\right] \tag{1.14}$$

where $\overline{\pi}_i$ and $\overline{q}_k$ designate the profit and the optimal level of remanufacturability under environmental regulations. With $k \in \{nc, c\}$, equation (1.14) stands for either the non-cooperative or the collusive case and respects the equilibrium condition which stays equation (1.11) or (1.13).

An environmental regulation will be *effective* if it is larger than voluntary remanufacturability, i.e. when $\overline{q} > q_k^*$. However, if a regulation applies to different industries with uneven remanufacturing initiatives, the regulation might be *non-effective* for some industries with $\overline{q} < q_k^*$. In this case, the regulation constraint is not biding and the selected level of remanufacturability stays unchanged. The applied level of remanufacturability and the difference in profits before and after regulation are:

$$\overline{q}_k = \begin{cases} q_k^* \text{ if } q_k^* \geq \overline{q} \\ \overline{q} \text{ if } q_k^* \leq \overline{q} \end{cases} \tag{1.15}$$

$$\overline{\pi}_i(\overline{q}_k) - \pi_i^*(q_k^*) = \begin{cases} \frac{(c_m(\overline{q}) - c_m(0))}{2} \text{ if } q_k^* \geq \overline{q} \\ \frac{(c_m(q_k^*) - c_m(0))}{2} + \sum_{t=1}^{b} \beta_i^t[\delta(r_i^*(\overline{q})^2 - r_i^*(q_k^*)^2)] \text{ if } q_k^* \leq \overline{q} \end{cases} \tag{1.16}$$

Figure (1.3) shows how profits vary with the imposition of a regulation. The difference between the curves $\overline{\pi}_i(\overline{q}_k)$ and the horizontal lines $\pi_i^*(q_k^*)$ describes the difference in profits due to all possible levels of regulation. The light and medium shade areas show the non-cooperative case while the medium and dark shade areas exhibit the collusive case.

When the regulation is non-effective (i.e. when $\overline{q}_k = q_k^* \geq \overline{q}$), the level of remanufacturability stays unchanged. However, the OMs' profit increases by $(c_m(\overline{q}) - c_m(0))/2$ due to the higher original product price, partially shifting the cost of remanufacturability towards final good producers and consumers. When a social utility function that equally weights producers' profits and consumers' surpluses is considered, this money transfer leaves the social welfare unchanged.

An effective regulation ($\overline{q}_k = \overline{q} > q_k^*$) influences OMs' profits through two effects. First, price and cost are now equal on the primary market and OMs' initial deficit vanishes. This shifts up profits by $(c_m(q_k^*) - c_m(0))/2$. Second, a higher level of remanufacturability influences OMs' technological advantage and, consequently, their ability to reach a larger aftermarket share (equations (1.9) and (1.10)). As long as the OMs gain technological advantage, $c_s'(\overline{q}) - c_r'(\overline{q}) \geq 0$, their profits increase. When $c_s'(\overline{q}) - c_r'(\overline{q}) \leq 0$, the technological gap lessens and OMs see their aftermarket share reduced. Thereafter, the profit under regulation decreases until it reaches the initial firm's profit $\pi_i^*(q_k^*)$ at $\overline{q} = \overline{q}_k^{\max}$, where the second effect overtakes the first one. Above this threshold, regulation results in net costs for the OMs.

Proposition 2 *Environmental regulations can be complementary to firms' benefits for both the non-cooperative and the collusive cases:*

$$\overline{\pi}_i(\overline{q}_k) - \pi_i^*(q_k^*) > 0 \iff \overline{q} < \overline{q}_k^{\max}.$$

In particular, this remains true when the environmental regulation is effective:

$$\overline{\pi}_\imath(\overline{q}_k) - \pi_\imath^*(q_k^*) > 0 \Longleftrightarrow q_k^* \leq \overline{q} < \overline{q}_k^{\max}$$

This result coincides with the Porter Hypothesis, which says that profits may increase in the industry with the application of environmental regulations. The present model corroborates the argument of Ambec and Barla (2007) under which the Porter Hypothesis requires the presence of at least one market imperfection beside the environmental externality. The phenomenon here is the result of two market characteristics.

The first is the threat of the outsider on the primary market, which keeps the original price at the minimum production cost. Hence, OMs cannot pass on the information through prices that a product is remanufacturable. The competitive final good producers do not benefit from remanufacturability and see no incentive in raising production costs. Therefore, the selling price stays $p_m = c_m(0)$. When the regulation takes place, the selling price p_m carries the information up to the point justified by the public intervention ($p_m = c_m(\overline{q})$). This result shows how free-entry on the original alternator market has prevented OMs from engaging in remanufacturing initiatives and how the asbestos ban was welcomed by the industry.

The second characteristic occurs in the non-cooperative scenario. From *Proposition 1*, it is known that collusion leads to higher profits. Here, the regulation solves for this collective action problem. Although non-cooperation is not a necessary condition in confirming the Porter Hypothesis, it increases the extent to which regulations generate profits. This specific effect is graphically represented in Figure 1.3 by the area framed above and below by the horizontal lines $\pi_\imath^*(q_c^*)$ and $\pi_\imath^*(q_{nc}^*)$, and to the left by the curve $\pi_\imath^*(q)$. André *et al.*

(2009) obtains similar results when a duopoly simultaneously choose between the production of a "standard" or a "green" product. A discrete choice of options can keep the standard quality as the Nash equilibrium, even if Pareto dominated by the green choice. Therefore, a regulation that forces cooperation between firms for the environmentally-friendly option can benefit firms, consumers and the environment. This additional role given to the regulation explains the difference between the non-cooperative and the collusive scenarios and leads to propositions 3 and 4.

In view of the positive variation in profits, any regulation below $\overline{q}_k^{\max}$ should be positively supported by the OMs. In contrast, regulations above $\overline{q}_k^{\max}$ are likely to meet resistance in their application. The difference in profits before and after the regulation (equation (1.16)) can therefore be interpreted as the *intensity* of compliance or resistance towards the regulation. Hence:

Proposition 3 *It is always easier to introduce an environmental regulation* $\overline{q}$ *under the non-cooperative case:*

$$\overline{\pi}_\imath(\overline{q}_{nc}) - \pi_\imath^*(q_{nc}^*) > \overline{\pi}_\imath(\overline{q}_c) - \pi_\imath^*(q_c^*)$$

Proposition 4 *The maximum level of regulation positively supported by the industry is larger under the non-cooperative case:*

$$\overline{q}_c^{\max} < \overline{q}_{nc}^{\max}.$$

In the absence of environmental regulation, the government can promote collusion as a substitute for regulation. However, when a regulation is scheduled, collusion should be repressed since non-cooperation better supports the regulation.

1.4.2 Intervention maximizing OMs' profit

Let $\overline{q}^*$ denotes the optimal regulation that would be chosen by the OMs. This scenario differs from the collusive case in the absence of regulation; for whichever level of remanufacturability chosen by the OMs, the outsider, constrained by the regulation, will not have the opportunity to produce at lower costs and, consequently, the threat vanishes. With $p_{m1} = p_{m2} = c_m(\overline{q})$, the maximization problem is:

$$\max_{\overline{q}\geq 0} \overline{\pi}_\imath = \sum_{t=1}^{b} \beta_l^t [\delta r_\imath^*(\overline{q})^2]$$
$$\text{s.t. } r_\imath^*(\overline{q}) = \frac{\delta + c_s(\overline{q}) - c_r(\overline{q})}{3\delta}.$$

The optimal condition is:

$$\frac{\partial \overline{\pi}_\imath}{\partial q} = 0 \Longleftrightarrow c_s'(\overline{q}^*) - c_r'(\overline{q}^*) = 0 \tag{1.17}$$

and the second-order condition is always satisfied. Note that $\overline{q}^*$ coincides with $\widehat{q}$, the level of remanufacturability that maximizes the OMs' technological advantage (see equation (1.10)). Figure 1.3 displays $\overline{q}^*$ and $\overline{\pi}_\imath(\overline{q}^*)$, the privately optimal regulation and the corresponding profit. Comparing the optimal conditions for the determination of $\overline{q}^*$, q_c^* and q_{nc}^* leads to the following propositions:

Proposition 5 *The regulation preferred by the private sector leads to a level of remanufacturability above the one chosen in absence of regulation:*

$$\overline{q}^* > q_c^* > q_{nc}^*$$

Proof: From *Proposition 1*, it is already known that $q_c^* > q_{nc}^*$. The optimal conditions (1.11) and (1.13) for the choice of q in absence of environmental regulation imply a positive value of $(c_s'(q) - c_r'(q))$. Since $c_s''(q) - c_r''(q) < 0$ in this neighbourhood (equation (1.10)), it is straightforward to see that the condition leading to the private optimal choice of regulation (1.17) results in $\overline{q}^* > q_c^* > q_{nc}^*$.

Proposition 6 *The size of remanufacturing activities (for the OMs) is maximized if and only if the public sector fixes the regulation at the level preferred by the OMs:*

$$\frac{\partial r_i^*}{\partial \overline{q}} = \frac{(c_s'(\overline{q}) - c_r'(\overline{q}))}{3\delta} = 0 \Longleftrightarrow \overline{q} = \overline{q}^*$$

When the regulation is selected by the private sector, OMs take into account the fact that the entire production cost is covered by the selling price. They can therefore seize the maximum aftermarket share by costlessly choosing the level of remanufacturability leading to their largest technological advantage. When $\overline{q} = \overline{q}^*$, OMs's profits are maximized as well as their aftermarket size.

When OMs' remanufacturing activities pollute significantly less than IRs', the social planner may want to maximize the OMs' aftermarket share to the detriment of higher remanufacturability by choosing $\overline{q} = \overline{q}^*$.

1.4.3 Note on the consumer surplus

Through the original market, any regulation will have a negative impact on the consumer surplus since it shifts, totally or partially, the cost of remanufacturability $(c_m(\overline{q}) - c_m(0))$ towards consumers. However, on the aftermarket, a higher level of remanufacturability has a positive effect because it reduces replacement products' prices through lower remanufacturing costs (this can be found using equations (1.2), (1.3) and (1.8)). Consumer surplus will also vary with the share of high quality goods $2r_i^*$. It can be shown that the level of remanufacturability maximizing consumer surplus on the aftermarket is larger than the environmental regulation maximizing OMs' profit.[18]

When combining the consumer surplus on both the original market and the aftermarket, the overall effect of an environmental regulation is ambiguous.

1.5 Conclusion

Original manufacturers produce a component as an input for the final good where the threat of an outsider keeps the input's price at the minimum production cost. At the same time, they select the technology determining the level of remanufacturability of their products. Later, consumers of the final good have to replace the specific component. They consider

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[18] Because consumers' willingness to pay on the aftermarket shows an explicit form, it is possible to find the level of remanufacturability maximizing the consumer surplus on this market, q_{cs}^*. Referring to Figure 1.1, total consumer surplus is formally defined by: $S = \sum_{t=1}^{b} \beta_l^t \left[\int_{\theta_q}^{1} (\theta + \alpha - p_r)\partial\theta + \int_0^{\theta_q} ((1-\delta)\theta + \alpha - p_s)\partial\theta\right]$. Markets clear in equilibrium, therefore $1 - \theta_q = 2r_i^*$. Using (1.2), (1.3) and (1.8), the total consumer surplus for a given q becomes: $S(q) = \sum_{t=1}^{b} \frac{\beta_l^t}{2} \left[(1-\delta) + \delta 2r_i^*(q)^2 + 2(\alpha - c_s(q))\right]$, and the first-order condition is: $\delta 2r_i^*(q_{cs}^*)\partial r_i^*(q_{cs}^*)/\partial q - c_s'(q_{cs}^*)) = 0$. Using equations (1.9), (1.10) and (1.17), it is shown that q_{cs}^* occurs in a range where the technological advantage decreases and that $q_{cs}^* > \overline{q}^*$.

products remanufactured by either independent remanufacturers or original manufacturers, and they are willing to pay a price premium for the latter. In this set-up, used products can be remanufactured by any firm, causing original manufacturers to suffer from free-riding on their technology selection and discourages investment in remanufacturing-oriented designs. When the original manufacturers collude on the level of remanufacturability, they only face the externality of independent remanufacturers and select a higher level of remanufacturability.

Remanufacturing benefits the population through less post-consumption waste, lower energy and raw material consumptions, and lower prices for replacement products. It also benefits the industry through the generation of positive profits. While the gains of remanufacturing are shared among the society, the costs of remanufacturing-oriented technology are born solely by the original manufacturers. Consequently, public regulation is necessary.

The introduction of an environmental regulation, which imposes a minimal level of remanufacturability, justifies a price increase on the primary market. As a consequence, the cost of complying with the regulation is redirected towards final good producers and consumers. Hence, original manufacturers can see their profits increase. This observation corroborates the Porter Hypothesis.

A social planner who wants to stimulate remanufacturing activities can consider allowing private collusion as an alternative to environmental regulation since it leads to a higher level of remanufacturability and, indirectly, to a larger supply of high quality remanufactured products. However, the social optimum can be achieved through the application of an environmental regulation that reduces the threat of the outsider and solves for the collective action problem. If the social planner opts for this option, it should repress private collusions. When the variation in profits following the public intervention is interpreted as the industrial degree of cooperation with the regulation, original manufacturers will always offer stronger support, or lower opposition, when the technology choice is initially subject to free-riding.

Chapter 2
Transboundary movements of waste

2.1 Introduction

The phenomenon of transboundary shipment of waste is driven by the scarcity of traditional landfill capacity in industrialized countries, where post-consumption waste has become a major concern. Governments have recently introduced new types of regulations, called extended producer responsibility, which make firms and producers responsible for waste disposal costs. The European Union's Directive on Waste Electrical and Electronic Equipment (WEEE) introduced in 2005 is an example. When firms internalize the cost of eco-friendly waste disposal, they tend to reduce the use of hazardous material and improve the reusability of their products. Also, some regulations directly aim at improving the quality of waste, like the European Union's End of Life Vehicle Directive introduced in 2006, which stipulates that every new vehicle must have recyclable content of 85 percent (95 percent by 2015). The current paper analyzes the impact of such regulations[19] when trade of used products is allowed for.

Although there are second-hand good markets in developed countries, the demand for such goods is often low due to technological obsolescence or regulations (like the technical inspections in many European countries that ensure that vehicles in poor conditions must be taken off the road). However, due to the gap in wealth between industrialized and

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[19] For more details on the different instruments see Toffel *et al.* (2008).

industrializing economies, developing countries have a positive demand for some products that would be defined as waste in the North. This is the case of many e-waste, used vehicles[20] and recycled materials [Janischweski *et al.* 2003, Beukering and Bouman 2001]. In addition, industrial processes which reuse waste are typically qualified as labor-intensive. Therefore, there is a natural movement of waste from developed to less developed countries.

Two important sets of regulations govern transboundary movements of waste. The Basel Convention and EU regulations both restrict the shipment of waste and their disposal. So as to minimize the environmental impact of waste management, the export of hazardous waste, e-waste and used vehicles from OECD to non-OECD countries is prohibited. However, the difference in the treatment and disposal costs remains one of the driving forces for transboundary shipments. Non-OECD countries often have low-cost, albeit environmentally inadequate, facilities. Czarnomski and Webb (2006) give the example of a PC monitor that costs around £5 to be recycled in the UK versus traders willing to pay up to £3 for a "visibly undamaged" monitor. The export of such e-waste to non-OECD countries often ends up incinerated in open fires, a practice which is unsafe both for the environment and human health [EEA 2009].

When combining i) the difference in local waste regulations, ii) the labor intensity of waste reuse industries and iii) the demand-driving forces, developing countries possess all the necessary characteristics to be pollution havens. Because of environmental concerns

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[20] Janischweski et al. (2003) show that countries in East and West Africa import more second-hand vehicles than new ones. These cars have a particularly poor quality and are often more than 15 years old.

in the North, stricter environmental regulations are implemented and increase production costs of dirty industries (waste management) at home. The Pollution Haven Hypothesis stipulates that dirty industries will migrate from developed to less developed countries.

In order to minimize the cost of complying with extended producer responsibility programs, firms may consider legal and illegal[21] shipments of waste. The New York Times reporter Elisabeth Rosenthal (September 27, 2009) has investigated this market. She reports that, according to expert's *estimation*, around 16 percent of the exports are illegal. She also underlines that fewer restrictions on waste exports in the United States and Canada produce a large flow of waste legally exported to developing countries. Other sources say that illegal shipments *reported* by non-OECD countries are in average 22 000 tonnes per year, which represents 0.2 percent of notified waste [EEA 2009]. These illegal activities take different forms: transporting waste on the black market, mixing different types of waste or declaring hazardous waste as non-hazardous. This research concentrates on yet another type of illegal practice: classifying waste as second-hand goods. When products are classified as second-hand goods, they are no longer governed by international waste regulations and can be traded with developing countries.

There are two used good market characteristics that I refer to as the *lack of international vigilance*. The first one is that second-hand goods appear to be a one-size-fits-all category for recyclable, remanufacturable and second-hand products. As a result of these institutional ambiguities, international waste regulations are subject to different interpretations. Hence, authorities and enforcement agencies of the countries misclassify waste as

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[21] The United States have fewer restrictions on waste exports than Europe because they did not ratify the Basel convention. As a result, waste shipments are generally legal.

used goods [Fischer *et al.* 2008]. Such misclassifications have been observed for e-waste and used vehicles[22] [Czarnomski *et al.* 2006 and Janischweski *et al.* 2003], and also for used clothes, car tires and other types of waste [Fischer *et al.* 2008]. Authorities from developing countries can also turn a blind eye to this illegal market. Reluctant to improve monitoring, they prefer to protect the imported waste business and the labor market it generates [Yardley, April 23, 2010].

The second characteristic qualified as the lack of international vigilance is that many used products are traded along with new ones. This situation makes it hard to keep track of them. One way to evaluate the scale of these markets is to compare prices. For instance, the average price of all exported television sets from Europe is 339€ whereas the price drops to 28€ when exported to Nigeria, Ghana or Egypt (where more than 1 000 used television sets arrive every day) [EEA 2009]. For both waste and used goods, the lack of precision in this identification renders market analysis difficult [EEA 2009].

The United-States and India, along with other countries, have led discussions during the Doha round. They want the WTO to undertake initiatives in order to regulate the movement of used products. Today, the WTO has only a draft version of proposed legislation, in which it is recommended that the import of used products be banned. As a result, developed countries see the market for their used products reduced.[23] Under proper regula-

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[22] Czarnomski *et al.* (2006) observes that a significant amount of what is considered WEEE in OECD countries is exported illegaly to West Africa as second hand goods. Also, Janischweski *et al.* (2003) note that transactions where vehicles exported in "top condition" happen to be "cars without an engine" are so common that they name it the Lemon Rule.

[23] While some countries forbid the import of used goods, others apply prohibitive tariffs. Uganda qualifies used goods as sensitive and applies a tariff of 55%, beyond the common external tariff of 25%. (See www.allafrica.com, 12 February 2009)

tions, there is potential for gains from liberalizing trade in used goods as shown in Clerides (2008).

One rationale behind extended producer responsibility programs is that, by internalizing the cost of waste disposal, firms choose a higher level of reusability. The current paper observes the effect of higher disposal costs in the presence of an international second-hand goods market. In a stylized North-South model, a representative firm in the South can purchase second-hand products from the firm in the North as intermediate goods. Because of a lack of international vigilance, illegal shipments of non-reusable waste are mixed with the exported goods. The model explores the driving forces of illegal waste movements with particular attention to differences in local disposal costs. It also observes the impact of higher international vigilance. Results show that a large difference in waste treatment costs can induce firms in the North to reduce the reusability of their products. An increase in international vigilance can also bring counterintuitive results.

Few authors have studied extended producer responsibility programs. Runkel (2003) studies the influence of four instruments on product durability and welfare. He also explores different competitive environments and shows that the application of an extended producer responsibility program under imperfect competition can lead to a welfare reduction. Fleckinger and Glachant (2010) are concerned with the fact that such programs are precisely designed in order for producers to meet their obligations in their own way. They study a duopoly of producers and compare scenarios where producers manage their waste on their own and where they cooperate through a recycling center (called producer responsibility organization). They conclude that such a cooperation could lead to suboptimal outcomes and justifies government intervention.

The theoretical literature on trade in used products is still very scarce. Bond (1983) develops a model based on differences in factor prices and technologies in order to explain trade in equipment between firms. He also tests it empirically. The empirical literature on the topic is more common with Frazer (2008) who explains the decline in apparel production in Africa through used-clothing donations,[24] or Clerides (2008) who describes the gains from trade in used vehicles. To the best of my knowledge, the current paper is the first research project which integrates movements of illegal and reusable waste into an economic model.

Section 2.2 introduces the model and section 2.3 solves for the equilibrium. Section 2.4 presents effects of a change in the disposal cost in the North as well as the consequences of stricter enforcement in international vigilance. Section 2.5 concludes.

2.2 The Model

The problem is set in a basic model of international trade where a representative firm in a developing country (the South) imports inputs (used products) from the firm in the developed country (the North).

New final goods are produced in quantity x_N by a monopolist in the North and they are consumed at home. At the end of the products' lifetime, the firm is subject to an

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[24] Similar to food aid, used-clothing imports harm local producers. The problem of used good imports as an obstacle for economic development is also largely discussed in Janischweski *et al.* (2003).

extended producer responsibility program. In order to comply with the regulation, the firm creates a recycling center[25] recognized by the government, which manages the collection and the disposal of e-waste. The firm is both client and owner of the recycling center. For simplicity, the recycling center's activities will be merged in the firm's objective function.

A portion of the used products are classified as reusable and can be exported to the South as an input to their production. The North exports w_e used goods at price p_e^w. The subscript e refers to the export values. The rest must be disposed in an eco-friendly manner, at constant unit cost of disposal d_N. The firm can also increase the fraction of reusable products q at an increasing and convex unit cost $c_N(q)$.

The firm faces decreasing inverse demand for its new products:

$$p_N = \beta - x_N,$$

where β represents the North's market size.

The firm in the South is a representative firm of a market in perfect competition. It employs used products as an input where x_S final goods are sold at exogenous price p_S. The firm can either apply some transformation processes like cleaning, remanufacturing or repairing; or it can act as an intermediary in shipping, handling and reselling. One used

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[25] For instance, in France, four recycling centers are recognized today by the government in order to comply with the WEEE directive. Eco-systèmes gathers many stockholders like LG, Moulinex, Philips and Samsung (see www.eco-systemes.com) while the European Recycling Platform was founded by Braun, Electrolux, HP and Sony (see www.erp-recycling.org). The two others are Ecologic (see www.ecologic-france.com) and Recylum (www.recylum.com). The last one treats only used lamps.

In the curent model, the assumption of a monopolist in the North recalls the assumption of Fleckinger and Glachant. They argue that recycling centers bring a risk of collusion and they explore this issue. Producers collude perfectly and choose the quality (related to the q here) that would be selected in the monopolistic case.

Since trade with the South passes through the recycling center, the assumption captures also the North's market power *vis-à-vis* the firm in the South.

good is necessary for the production of one output. Production costs are divided in three parts. First, they have to acquire used products from the North. They buy a basket (or a container) of these used products that are previously classified as reusable. They pay p_m^w for each of the w_m imported good. The subscript m refers to the import values.

q denotes the proportion of goods x_N that are reusable at the end of their lives. The proportion $1-q$ is non-reusable and, under international regulations, should not be exported to the South. However, the lack of international vigilance causes a fraction $\sigma \in (0,1)$ of these non-reusable goods to be misclassified. The actual fraction of used goods classified as reusable is:

$$\mathring{q} = q + (1-q)\sigma$$

As a result, in the basket of imported goods, only a fraction $\overline{q} = q/\mathring{q}$ can be used as inputs. $\overline{q}$ is referred to as the *purity* of the basket.[26]

The second part of production costs reflects the sorting and the transformation processes, which decreases with $\overline{q}$. The representative firm has perfect information about the purity of baskets. Once sorted as reusable, goods require different degrees of intervention – from simple cleaning to change in parts – and the marginal cost increases with x_S. These transformation costs take the form: $c_S(x_s; \overline{q}) = x_s^2/2\overline{q}$.

The South can also adopt an extended producer responsibility program d_S which constitutes the third part of total costs. It is assumed that the South has laxer environmental regulations so that their waste disposal cost is lower than in the North: $d_S \leq d_N$.

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[26] It is assumed that the monopolist does not sort waste in order to improve purity. Sorting is a labor intensive activity and is hence too costly for the firm in the North. As a result, purity depends only on the level of reusability q.

2.2.1 The market structure

The market structure is described by the following two stage game. Local disposal costs, d_S and d_N, and the state of international (lack of) vigilance, σ, are given. In the first stage, the monopolist firm in the North produces new goods in quantity x_N and selects the level of reusability q. The firm also selects the level of exports, w_e.

The representative firm in the South is a price taker on the international market. In the second stage, the level of imports as well as the quantity of output, w_m and x_S, are determined in the South.

Since the firm in the North is the leader, its decision when selecting the level of exports incorporates the representative firm's reaction function.

2.3 The equilibrium

The profit functions for the firm in the North and in the South are respectively:

$$\begin{aligned}
\pi_N &= p_N x_N - c_N(q)x_N + p_e^w w_e - (x_N - w_e)d_N \\
&\quad \text{where } p_N = \beta - x_N \\
&\quad \text{and } w_e \leq \mathring{q} x_N \qquad (2.18) \\
\pi_S &= p_S x_S - c_S(x_S;\overline{q}) - (p_m^w + d_S)w_m \\
&\quad \text{where } c_S(x_s;\overline{q}) = x_s^2/2\overline{q} \\
&\quad \text{and } x_S \leq \overline{q} w_m \qquad (2.19)
\end{aligned}$$

Equation 2.18 means that the monopolist cannot export more than the proportion of used goods classified as reusable. It is assumed that the international market is small enough so that equation 2.18 is not binding in equilibrium. The scenario of a corner solution, when the South imports all goods classified as reusable is not considered here.[27] Equation (2.19) says that the firm's output in the South is limited by the amount of reusable inputs $\overline{q}w_m$.

Using backward induction, the final stage is solved first. The representative firm's problem is:

$$\max_{w_m} \pi_S = p_S\overline{q}w_m - \left(\overline{q}w_m\right)^2/2\overline{q} - (p_m^w + d_S)w_m$$

$$\text{s.t. } x_S \leq \overline{q}w_m.$$

In equilibrium, the constraint is binding

$$x_S = \overline{q}w_m \tag{2.20}$$

and the first order condition leads to the following reaction demand function for imported goods:

$$p_m^w = p_S\overline{q} - w_m\overline{q} - d_S. \tag{2.21}$$

In equilibrium, the international market clears:

$$w_m = w_e = w \text{ and} \tag{2.22}$$

$$p_m^w = p_e^w = p^w. \tag{2.23}$$

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[27] It implies that β is large enough. Formally, $\beta > (p_s\overline{q} + d_N - d_S)\,\frac{2+2\overline{q}\overset{\circ}{q}^2}{q} + c_N(q) + d_N$.

The first stage in the game is the firms's problem in the North. Using equations (2.21) to (2.23), the monopolist's problem becomes:

$$\max_{w,x_N,q} \pi_N = (\beta - x_N)x_N - c_N(q)x_N + (p_S\overline{q} - w\overline{q} - d_S)w - d_N(x_N - w).$$

The first order conditions lead to:

$$\begin{aligned} w &= \frac{p_S\overline{q} + d_N - d_S}{2\overline{q}} && (2.24) \\ x_N &= \frac{\beta - c_N(q) - d_N}{2} && (2.25) \\ \frac{\partial \pi_N}{\partial q} &= (\beta - c_N(q) - d_N)\frac{-c'_N(q)}{2} + \frac{\partial \overline{q}}{\partial q}\left(\frac{(p_S\overline{q})^2 - (d_N - d_S)^2}{4\overline{q}}\right) = 0 && (2.26) \end{aligned}$$

Where equation (2.24) is the level of exports, (2.25) is the production of new goods and (2.26) is the optimality condition for the choice of reusability q. It is assumed that the second order condition for a maximum is satisfied.[28] Using equations (2.21) to (2.25), the price of exports becomes:

$$p^w = \frac{p_S\overline{q} - d_N - d_S}{2} \qquad (2.27)$$

The equilibrium in this industry is characterized by equations (2.20) to (2.27). For the purpose of the analysis, illegal shipments, which is the non-reusable share of exports, take the form:

$$(1 - \overline{q})w$$

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[28] $\frac{\partial^2 \pi_N}{\partial q^2} = \frac{c'_N(q)^2}{4} - (\beta - c_N(q) - d_N)\frac{c''_N(q)}{2} + \frac{\partial^2 \overline{q}}{\partial q^2}\left(\frac{(p_S\overline{q})^2 - (d_N - d_S)^2}{4\overline{q}}\right) + \frac{\partial \overline{q}}{\partial q}\left(\frac{(p_S\overline{q})^2 + (d_N - d_S)^2}{4\overline{q}}\right)$

2.4 Disposal cost and international vigilance

2.4.1 Disposal cost and the Pollution Haven Hypothesis

One of the rationales behind extended producer responsibility is that, by internalizing the cost of waste disposal, firms choose a higher level of reusability. Let us see what happens, in the presence of a secondary market in developing countries, when the North applies higher disposal costs.

We have:

$$\begin{aligned} \text{sign}\frac{\partial q}{\partial d_N} &= \text{sign}\frac{\partial^2 \pi_N}{\partial q \partial d_N} \text{ where} \\ \frac{\partial^2 \pi_N}{\partial q \partial d_N} &= \frac{c_N'(q)}{2} + \frac{\partial \overline{q}}{\partial q}\left(\frac{-2\left(d_N - d_S\right)}{4\overline{q}}\right). \end{aligned} \tag{2.28}$$

Proposition 7 *For all* q*, there exists a unique* $\phi > 0$ *such that*

$$\frac{\partial q}{\partial d_N} \gtreqless 0 \iff d_N - d_S \lesseqgtr \phi$$

in particular, for $d_N - d_S = 0$*,* $\partial q / \partial d_N > 0$*. Note that* ϕ *depends on the initial value of* q*, determined by the equilibrium prior to the change in policy.*

Proof. We know that $c_N'(q)$ and $\partial \overline{q} / \partial q$ are positive. Therefore, equation (2.28) strictly decreases when $d_N - d_S$ increases. Since $\partial q / \partial d_N > 0$ when $d_N - d_S = 0$, then $\partial q / \partial d_N = 0$ when $d_N - d_S = \phi > 0$. ■

One can see that when the South regulates as much as the North, i.e. $d_N = d_S$, the level of reusability q increases unambiguously with the strength of local waste regulation d_N. However, when the difference in disposal costs is large enough, more stringent waste regulation in the North reduces the choice of reusability and induces an increased amount of illegal shipments. These observations are explicitly formulated in the following proposition.

Proposition 8 *In equilibrium, the effect of an increased disposal cost in the North* d_N *depends on the difference between local disposal costs,* $d_N - d_S$*:*

- *When the extended producer responsibility is similar between the two countries, i.e. when* $d_N - d_S < \phi$*, the firm in the North, which internalizes the South's disposal cost, does not benefit from a large difference between local and foreign disposal costs. Therefore, the firm will increase the level of reusability of its products* q *and propose baskets with higher purity* $\overline{q}$*. Because exports are potentially higher, the total effects on the amount of illegal shipments,* $(1-\overline{q})w$*, as well as on the price of exports* p^w*, are ambiguous.*
- *When the extended producer responsibility is largely different between the two countries, i.e. when* $d_N - d_S > \phi$*, the firm in the North benefits from a large difference between its local disposal cost and the internalized South's cost. The monopolists' strategy will therefore aim at exporting non-reusable goods, cheaper to be disposed of in the South. The firm in the North will reduce the reusability of its products* q *and reduce the purity of exported baskets* $\overline{q}$*. This strategy lowers the price of exports* p^w *and causes an increased demand of used goods. With a higher level of exports and lower purity, illegal shipments* $(1-\overline{q})w$ *increase unambiguously. If purity were to stay high, the demand in the South would get saturated quickly and*

the level of exports would remain too low relative to the increasing disposal cost in the North and the possibility to "dump" non-reusable waste in the South.

In the light of Proposition 8, the initial intention of an extended producer responsibility program is respected when the difference in local regulations shows little difference. As the disposal cost increases in the North, the monopolist is more likely to consider illegal shipments instead of improving the level of reusability. This result is in line with the pollution haven hypothesis since the difference in environmental regulation between developed and less-developed countries brings a flow of pollution (waste) towards poor countries.

2.4.2 International vigilance

This section presents what occurs when international vigilance increases. We have:

$$\text{sign}\frac{\partial q}{\partial \sigma} = \text{sign}\frac{\partial^2 \pi_N}{\partial q \partial \sigma} \text{ where}$$

$$\frac{\partial^2 \pi_N}{\partial q \partial \sigma} = \frac{\partial^2 \overline{q}}{\partial q \partial \sigma}\left(\frac{(p_S \overline{q})^2 - (d_N - d_S)^2}{4\overline{q}}\right) + \frac{\partial \overline{q}}{\partial q}\frac{\partial \overline{q}}{\partial \sigma}\left(\frac{(p_S \overline{q})^2 + (d_N - d_S)^2}{4\overline{q}}\right) \tag{2.29}$$

The second term in equation (2.29) is always negative. It represents the variation in the marginal revenue of exports due to a variation in the terms of trade. All else equal, as vigilance increases (σ decreases), purity increases as well as the marginal revenue of each exported unit. The first term represents the variation in the marginal revenue of exports due to a variation in the marginal effect of the level of reusability q. Looking at the optimality condition for the choice of q (equation 2.26), we know that $(p_S \overline{q})^2 - (d_N - d_S)^2$ is positive in equilibrium.

Proposition 9 *There exists $\rho > 0.5$ such that*

$$\frac{\partial q}{\partial \sigma} \gtreqless 0 \Longleftrightarrow \overline{q} \gtreqless \rho$$

The effect of an increase in international vigilance (a reduction in σ) on reusability q depends on the initial value of purity $\overline{q}$, prior to the change in policy:

- *When the initial purity is small, i.e. when $\overline{q} < \rho$, an increase in international vigilance unambiguously leads to an improvement in the level of reusability.*
- *When the initial purity is large, i.e. $\overline{q} > \rho$, an increase in international vigilance leads to a reduction in the level of reusability.*

Proof. Looking at equation (2.29), we see that $\frac{\partial q}{\partial \sigma} > 0 \Leftrightarrow \frac{\partial^2 \overline{q}}{\partial q \partial \sigma}\left(-\frac{\partial \overline{q}}{\partial q}\frac{\partial \overline{q}}{\partial \sigma}\right)^{-1} > \frac{(p_S\overline{q})^2+(d_N-d_S)^2}{(p_S\overline{q})^2-(d_N-d_S)^2}$. For the specific form of $\overline{q}$, the left hand side increases asymptotically with the initial value of $\overline{q} \in (0,1)$ (for a given $\overline{q}(q,\sigma)$, obtained by any combination of q and σ, the left hand side is constant) and is positive if only if $\overline{q} > 0.5$ since

$$\partial^2\overline{q}/\partial q \partial \sigma \lesseqgtr 0 \Leftrightarrow \overline{q} \lesseqgtr 0.5. \tag{2.30}$$

The right hand side is positive and decreasing in $\overline{q}$. Therefore, ρ exists and occurs at $\rho > 0.5$. ■

When purity is large, equation (2.30) becomes positive, which means that, with an increase in international vigilance, an increase in the level of reusability has a smaller effect on purity. When purity is large enough, this incites the firm in the North to reduce the level of reusability.

Most variables of interest in this model depend on purity $\overline{q}$, which varies not only with the level of reusability q, but also with international vigilance σ. A change in international vigilance affects purity directly through $\partial\overline{q}/\partial\sigma$ and indirectly through $(\partial\overline{q}/\partial q) * (\partial q/\partial\sigma)$. When an increase in international vigilance leads to a reduction in reusability, the two effects work in opposite directions.

Proposition 10 *The total effect of an increase in international vigilance (a reduction in σ) on purity $\bar{q}$ is positive if only if*

$$\frac{d\overline{q}}{d\sigma} = \frac{\partial\overline{q}}{\partial q}\frac{\partial q}{\partial\sigma} + \frac{\partial\overline{q}}{\partial\sigma} \leq 0 \Longleftrightarrow \frac{\partial q}{\partial\sigma} \leq \frac{q(1-q)}{\sigma}.$$

The effects on trade and illegal shipments vary according to the following rule:

- *If $\frac{\partial q}{\partial\sigma} < \frac{q(1-q)}{\sigma}$, purity increases with international vigilance. In this case, the quantity of exports w decreases as well as illegal shipments, $(1-\overline{q})w$.*
- *If $\frac{\partial q}{\partial\sigma} > \frac{q(1-q)}{\sigma}$, purity decreases as international vigilance increases. In this case, the quantity of exports w increases as well as illegal shipments, $(1-\overline{q})w$.*

From Propositions 9 and 10, if purity is initially small, then it increases with international vigilance, i.e. $\overline{q} < \rho \Leftrightarrow \partial q/\partial\sigma < 0 < q(1-q)/\sigma$. If international vigilance keeps increasing, purity raises and eventualy becomes large when $\overline{q} > \rho$.

In some contexts, an improvement in international vigilance will have the opposite effect than what was intended from such a regulation. From Proposition 9, we know that this scenario occurs only when purity is initially high, i.e. $\partial q/\partial\sigma > q(1-q)/\sigma > 0 \Longrightarrow \overline{q} > \rho$. All else equal, improving international vigilance increases purity. The monopolist who wants to keep a lower level of purity will therefore reduce its level of reusability. When purity is already high, the benefit of reducing purity through q can be larger than the benefit, through the terms of trade, of keeping it high. In this case, more international vigilance intensifies illegal shipments.

2.5 Conclusion

This paper considers a North-South model where used durable goods in the North are imported by the firm in the South as an input to production. The lack of international vigilance allows for illegal waste to be mixed with reusable products.

In order to look at the Pollution Haven Hypothesis, special attention is given to large differences in local waste regulation between the two countries. It appears that the current application of extended producer responsibility programs, which makes producers responsible for the cost of waste disposal, opens up the valve to illegal shipments of waste. Conversely, trade with countries applying similar regulations would conserve the initial intention of such programs: more stringent regulations in the North leads to a higher level of reusability.

International vigilance also plays an important role. Better enforcement of international agreements leads to a reduction in illegal shipments of waste and an increase in the level of reusability. However, when the level of reusability is already high, better enforcement makes higher reusability less attractive. In some cases, lowering the level of reusability provides more benefit than the improvement in the term of trade. The producer using a high level of reusability would therefore present adverse behavior in case of improved international vigilance.

These results partially come from the fact that producers can manage their obligations in their own way. Because the recycling centers are owned by the producers, they have the incentive to export waste illegally in order to reduce the overall cost of waste disposal.

Chapter 3
Is democracy good for the environment? The role of private mitigation efforts

3.1 Introduction

This paper[29] compares the effects of several types of democratic and non-democratic regimes in terms of their implications for environmental regulation. We are seeking to explicitly frame and then to answer the question: Is democracy good for the environment?

In the economies analytically constructed, private mitigation of the consequences of pollution is available at a cost. Bottled water, water filtration system, air purifier, house location, vacation or medicines are examples of such private measures. The existence of such measures to defend ourselves against local pollution has often been noted in the literature[30] but has never been considered an endogenous factor in the study of the determinants of environmental regulation.

The role of private mitigation is critical in determining the extent to which elites (in non-democratic regimes) or citizens (in democracies) seek government regulation or collective action to deal with environmental degradation. The interests of individuals in

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[29] This chapter is based on a working paper coauthored with Louis Hotte and Stanley L. Winer. We all contributed equally.

[30] Eriksson and Persson (2003) consider a political-economy where environmental quality differs across individuals. They do not propose the possibility of private mitigation, but citizens are uniformly ordered so that the distribution of perceived environmental quality goes with income distribution. Hotte and Winer (2008) propose a theoretical model where private defence causes divergent preferences over the regulation level.

our framework do not depend on the capital-labor ratio, as in much of existing literature, but on income levels. The reason is that private mitigation depends on income, whatever its source and, in turn, influences the balance between public and private action and the equilibrium policy mix.

The regulation of trade openness is intimately bound up with the determination of environmental regulation.[31] A study by Hotte and Winer compares the demand for regulation in different trade regimes and finds that when the country specializes in the dirty or pollution generating good, the intensity of individual interests is accentuated when international trade is allowed for. The present paper will examine the consequences for the environment of alternative political regimes in small open economies where a tariff on imports is used as a proxy for trade openness. The importance of trade for both democratic and non-democratic countries[32] justifies such experiment.

Trade openness in such situations increases national income but also the pollution level and the opportunity cost of its regulation. Here the ability of richer people to better defend themselves against pollution is decisive. In all regimes, one way or another, people in these models can be said to be struggling over the size and the (environmental) quality of the pie. When the rich have better access to private mitigation, they prefer policies that would increase the size of the pie and then use private defence in order to reduce their exposure to pollution. Poorer people who have little access to private mitigation, if given a

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[31] For an overview of the literature see Pethig (1976), McAusland (2003), Copeland and Taylor (1994) and Chichilnisky (1994).

[32] For empirical evidence see Lim and Decker (2007).

voice, may sacrifice a part of their gross incomes to have a better quality of life.

Four political equilibria are analyzed where the two policies, environmental regulation and tariff, are settled. Technically speaking, the set of models explored involves appropriately changing the nature of constrained optimization problems. The first one is a totalitarian regime where the outcome is determined by the maximization of the utility of rich individuals only.

The second equilibrium is a fully democratic regime where the selection of environmental policies is modeled as a probabilistic spatial voting equilibrium. Applying the representation theorem allows the maximization of a particular weighted sum of utilities to be used to characterize the equilibrium.

The third and fourth, more complicated cases, deal with subordinate regimes inspired from Rodrick (1992). Here the elite control a large part of the political outcome, while keeping the political support of the population. This is modeled as Nash equilibria in simultaneous games[33] where the elite lead one policy dimension and the population have the power on the other policy dimension. In the first of two alternatives, the elite command trade openness in order to maximize their utility taking the level of regulation as given while the poor observe the tariff in place and choose their preferred environmental regulation. The second case is the one where the population express their preferences over the degree of trade openness while the rich select the regulation that maximizes their utility.

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[33] This differ from Rodrick who proposes a Stackelberg game where the government is the 'follower' and the privileged group is the 'leader'. This alternative will be analyze in future research.

Previous papers that endogenously determine environmental policies generally explore a uni-dimensional political equilibrium.[34] The multi-dimensionality in our models (involving both environmental and trade policy) involves several criteria in order to delineate which regime is the most environmentally-friendly. The degree of environmental regulation is the first criterion and the level of pollution generated, as a result of both regulation and trade, is the second. The two criteria may eventually lead to different conclusions.

Under a simulated economy that represents a possible particular case, there is a suggestion that subordinate governments may be more eco-friendly than a fully democratic regime. For instance, because they want to stimulate production, when the rich control trade openness they will choose a tariff lower than what would be selected in democracy. In order to keep its electorate, the subordinate government will compensate by opting for a higher regulation level. It is also shown that when the rich are more weighted in a democracy, subordinate regimes may be less polluting. Finally, a look at individual welfare suggests that institutional dynamic could pull the political outcome away from perfect democracy and towards a more eco-friendly equilibrium.

The paper is organized as follow. In the second section, we introduce the economic model with the possibilities of production and the emission of pollution through the dirty industry. Taking the level of regulation and the degree of trade openness as given, we also set the trade pattern for a small open economy in a general equilibrium framework. The third section exposes individual preferences over the consumption good and the private

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[34] For instance see McAusland (2003) and Eriksson and Persson (2003).

mitigation good. It also displays the preference functions which describe how the individual preference over one policy dimension varies with the other. By doing so, we also keep a close look at the influence of individual income on these preferences. In the fourth section, we analyze the political arena by explicitly exposing the optimization problem behind each political regime. Section five defines what we mean by the expression “good for the environment" and gives the first answers to the question “Is democracy good for the environment?". We conclude in section six.

3.2 Production, Pollution and Trade

3.2.1 Technologies

This small open economy is endowed with limited capacities of production that are used to produce two intermediate goods z_1^s and z_2^s. The production possibility frontier (PPF) has the following shape

$$z_2^s = (1-\theta)g(z_1^s), \tag{3.31}$$

where $g(\cdot) \geq 0$, $g'(\cdot) < 0$ and $g''(\cdot) < 0$. In the context of international trade, the superscript s refers to the local production of the intermediate goods which may differ from their demand. The parameter θ is the level of environmental regulation. Good z_2^s, called the dirty good, generates pollution in its production. The pollution generation function takes the form

$$P = h(\theta)z_2^s, \tag{3.32}$$

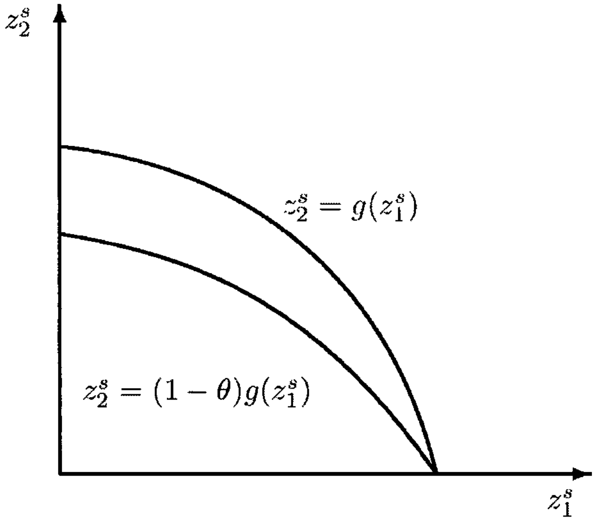

Fig. 3.4. Environmental regulation and production possibility frontier

where $h(\theta)$ is non-negative and decreasing. This function shows how θ, that can be interpreted as the cleanliness of the technology, reduces the effect of the dirty good production on the level of pollution. With $\theta \in [0,1]$, regulation decreases the capacities of production by shifting down the PPF (see Figure 3.4).

Alternatively, equation (3.32) can be written $P = h(\theta)(1-\theta)g(z_1^s)$ and can take the reduced form

$$P = \Gamma(\theta)g(z_1^s), \tag{3.33}$$

where $\Gamma(\theta) \equiv h(\theta)(1-\theta)$ is non-negative and decreasing.

The two intermediate goods are used in the production of a consumption good x and a private pollution mitigation good d. Their production follows a Cobb-Douglas form

$$x = x_1^a x_2^{1-a},$$

$$d = d_1^\beta d_2^{1-\beta},$$

where

$$z_1^d = x_1 + d_1,$$

$$z_2^d = x_2 + d_2.$$

Superscript d indicates the local demand for the intermediate goods to be used in consumption and private mitigation. In order to simplify the model, we assume that the pollution mitigation efforts are no more and no less pollution intensive than private consumption; that is, $a = \beta$. Hence, x and d have the same unit cost $C(p) = a^{-a}(1-a)^{a-1}p^a$.

Good 2 is the *numéraire* and the exogenous world price of good 1 is p^*. The local government may decide to impose a tariff $t \in [0, t_{max}]$ on imports so that the clean good is locally sold at price $p = p^* + t$[35]. Here t_{max} represents the tariff at which only the clean good is produced and it varies with the regulation level. The gross national product at market prices is composed of the incomes earned from production and from all indirect taxes (the tariff revenue):

$$I = pz_1^s + z_2^s + t(z_1^d - z_1^s), \tag{3.34}$$

where $z_1^d - z_1^s$ is the size of imports.

There are n individuals. Each receives a different share $\alpha_\imath$ of the total income, where $\alpha_\imath \in [0,1]$ and $\sum_{\imath=1}^n \alpha_\imath = 1$. This parameter can be interpreted either as a productivity index or a power scale that corresponds to the individual ability to appropriate productive resources. Tariff revenue as a source of redistribution is removed from the analysis to allow a focus on the welfare-trade-environment nexus. Therefore it is included in the total income and then redistributed as a lump-sum transfer in proportion to the pre-fisc income.

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[35] There is an equivalence between the tariff we use and a tax on the export of dirty goods (Lerner 1936).

The individual budget constraint is then

$$\alpha_i I = C(p)(x_i + d_i). \tag{3.35}$$

3.2.2 The economic general equilibrium with trade

We consider the case where the country partially specializes in the dirty production and imports the clean good; that is, $z_1^d - z_1^s \geq 0$. The general equilibrium with balanced trade for a small open economy is then defined by the following system:

$$p = -\frac{\partial z_2^s}{\partial z_1^s} = (1-\theta)(-g'(z_1^s)), \tag{36}$$

$$z_2^s = (1-\theta)g(z_1^s), \tag{37}$$

$$z_1^d = \frac{a}{p}I, \tag{38}$$

$$z_2^d = (1-a)I, \tag{39}$$

$$p = p^* + t, \tag{40}$$

$$I = pz_1^s + z_2^s + t(z_1^d - z_1^s), \tag{41}$$

$$P = \Gamma(\theta)z_2^s. \tag{42}$$

Equation (3.36) simply says that the production of good 1 is chosen such that the price is equal to the marginal rate of transformation. The respective demands for goods 1 and 2 (equations (3.38) and (3.39)) are the result of the Cobb-Douglas production function of x and d. The price (equation (3.40)) depends on the exogenous international price and the tax rate imposed by the government. By substituting (3.38) into (3.41), the total income can be rewritten as:

$$I = \frac{p}{p - ta}(p^* z_1^s + (1 - \theta) g(z_1^s))$$

Note that this whole system is independent of income distribution. Later on, regulation and tariff will be endogenously determined by the political equilibrium and will vary with individual income. Knowing that (3.37) always holds, we shall express z_2^s in terms of z_1^s for the rest of the paper.

3.2.3 Individual demands

Individual utility depends on a combination of the utility of consumption and the disutility of exposure to pollution. Each individual faces the following utility function:

$$V_\imath = \ln(x_\imath) - f(d_\imath, P).$$

The function $f(d_\imath, P) \equiv f_\imath$ is the exposure to pollution by individual $\imath$. It is decreasing and convex in private mitigation $d_\imath$ and increasing and convex in the level of aggregate pollution P. Also the assumption is made that the exposure function is separable in its two arguments, so that $\partial^2 f_\imath / \partial P \partial d = 0$.

The next section describes the individual choice of private mitigation. Sections 3.2.5 and 3.2.6 characterize the preferred level of regulation as well as the preferred tariff. The last section exposes the effects of a variation in income on these preferences.

3.2.4 Private mitigation

Individual $\imath$ maximizes welfare by choosing consumption bundles $x_\imath$ and $d_\imath$. Total income I, Pollution P, regulation θ, price level p as well as the tariff t, are all taken as given. The individual's behavior is described by:

$$\max_{x_\imath, d_\imath} V_\imath = \ln(x_\imath) - f(d_\imath, P)$$
$$\text{s.t}\, x_\imath = \frac{\alpha_\imath I}{C(p)} - d_\imath.$$

The first order condition for an interior solution is

$$\frac{1}{x_\imath^*} = -\frac{\partial f(d_\imath^*, P)}{\partial d_\imath} \tag{3.43}$$

which leads to the following optimal choice of x and d:[36]

$$x_\imath^* = -\left(\frac{\partial f(d_\imath^*, P)}{\partial d_\imath}\right)^{-1} \tag{44}$$
$$d_\imath^* = \frac{\alpha_\imath I}{C(p)} + \left(\frac{\partial f(d_\imath^*, P)}{\partial d_\imath}\right)^{-1}. \tag{45}$$

The choice is made such that the marginal utility of consumption $x_\imath$ is equal to the marginal diminution of exposure associated with the private defense $d_\imath$. For each individual, the basket $(x_\imath^*, d_\imath^*)$ is unique and depends on the share of income $\alpha_\imath$. For this private equilibrium to be consistent with epidemiologic studies which say that low-income individuals suffer more from the effects of pollution,[37] we assume that d^* is non-decreasing in income.

This model presents the existence of corner solutions. When the marginal effect of private mitigation is small, the poor who face large marginal utility of consumption could choose not to privately defend themselves against pollution with $d_\imath^* = 0$. Also, for some types of pollutant, the available private technologies will have neglectful effects on exposure. In this case, individuals would spend their entire budget on consumption goods

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[36] See appendix 3.A.1 for the second order conditions.

[37] For instance see Ash and Fetter (2004) or Pearce and al. (2006).

and the optimal solution would be

$$x_\imath^* = \frac{\alpha_\imath I}{C(p)} \text{ and} \tag{46}$$

$$d_\imath^* = 0. \tag{47}$$

Yoo (2005) analyzes household expenditures in bottled water and water purifier. Because of the lack of credibility of tap water, these expenditures are increasing in Seoul, Korea. Among the sample, 84% had zero expenditure in the private substitutes but there was a significant and positive effect of income on the consumption of both bottled water and water purifiers. This example illustrates how the consumption path of a private mitigation good can evolve with an increase in the individual income. Interestingly, it shows how d can be characterized as a luxury good when an individual, who does not consume such a good at first, suddenly devotes to it a positive share of income.

3.2.5 The preferred level of regulation

Accounting for all general equilibrium effects, individual $\imath$ will have a preference for the regulation level $\theta_\imath^*$ if it respects the following condition, taking the degree of openness as given:

$$\frac{\partial V_\imath}{\partial \theta} = \frac{1}{x_\imath^*}\frac{\alpha_\imath}{C(p)}\frac{p}{p-ta}\left[-t\frac{\partial z_1^s}{\partial \theta}-g(z_1^s)\right]-\frac{\partial f_\imath}{\partial P}\left[\Gamma(\theta_\imath^*)g'(z_1^s)\frac{\partial z_1^s}{\partial \theta}+\Gamma'(\theta_\imath^*)g(z_1^s)\right] = 0 \tag{3.48}$$

The result to this equality implicitly gives the preference function $\theta_\imath^*(t)$. (See appendix 3.A.2 for more details.)

The term between the first brackets in equation (3.48) are two income effects of regulation. They account for the loss in consumption utility due first to a decrease in tariff revenue (production shifts towards cleaner productions and imports decrease) and then to abatement costs. The second term between brackets reveals the two negative effects of regulation on pollution. A direct effect with the use of a cleaner technology and an indirect effect with the diminution of z_2^s due to the higher opportunity cost of the dirty production.

In order to construct the political equilibrium, we must study the divergence of interests among the population. Using (3.48) and the implicit function theorem, we have

$$\frac{\partial \theta_i^*}{\partial \alpha_i} \lesseqgtr 0 \Leftrightarrow -\frac{\frac{\partial^2 V_i}{\partial \theta \partial \alpha_i}}{\frac{\partial^2 V_i}{\partial \theta^2}} \lesseqgtr 0. \tag{3.49}$$

If θ_i^* is a maximum, the denominator is negative and we have

$$\frac{\partial \theta_i^*}{\partial \alpha_i} \lesseqgtr 0 \Leftrightarrow \frac{1}{x_i^*}\frac{1}{C(p)}\frac{p}{p-ta}\left[-t\frac{\partial z_1^s}{\partial \theta} - g(z_1^s)\right](1-\epsilon_x) \lesseqgtr 0 \Leftrightarrow \tag{50}$$

$$\frac{\partial \theta_i^*}{\partial \alpha_i} \lesseqgtr 0 \Leftrightarrow \epsilon_x \lesseqgtr 1, \tag{51}$$

where $\epsilon_x \equiv \frac{\alpha_i}{x_i}\frac{\partial x_i}{\partial \alpha_i}$ is the income elasticity of good x (see appendix 3.A.3 for more details). This parameter indicates how a variation in income influences the proportion of income devoted to the consumption good. It captures all the information relative to individual preferences and the cost of private protection.

According to the empirical literature, it seems that for at least some technologies, support for environmental policies decreases with income, i.e. equation (3.51) adopts a negative sign. For instance, Kristrom and Riera (1996) use surveys on different environmental projects around Europe.[38] They show that in many cases, the hypothesis that the

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[38] They study the effect of income on the proportion of willingness to pay (WTP) in income. More specifically, they study the sign of $\frac{\partial(WTP/\alpha_i I)}{\partial \alpha_i}$. Considering the WTP as the individual opportunity cost of θ_i^*, in the present case we use $WTP = \alpha_i \int_0^{\theta_i^*} \frac{\partial I}{\partial \theta} \partial \theta$. We can show that $\frac{\partial(WTP/\alpha_i I)}{\partial \alpha_i}$ has the same sign as $\partial \theta_i^* / \partial \alpha_i$. For more details see appendix 3.A.6. This mathematical manipulation has also been used by McAusland

proportion of WTP in income decreases with income cannot be rejected. It would lead here to $\partial\theta_i^*/\partial\alpha_i < 0$.[39] Kahn and Matsusaka (1997) obtain similar empirical results. Studying the political support of citizens over 16 environmental projects in California, they show that $\partial\theta_i^*/\partial\alpha_i < 0$ among high-income voters.[40] The authors in both studies suggest that the existence of private substitutes available for richer people would be the explanation for such observations. This is highlighted in a study by Casey and al. (2006) which investigates the WTP of residents of Manaus, Brazil, for improved water service.[41] They demonstrate that people fully satisfied with their private well are less inclined to express positive support for a public water service. The condition under which private mitigation leads to a decrease in the demand for environmental regulation will be explicitly framed in Section 3.2.7.

3.2.6 The preferred degree of trade openness

Taking the regulation level as given, individual i will have a preference for the tariff t_i^* that is given by the following condition:

$$\frac{\partial V_i}{\partial t} = u_x \frac{\alpha_i}{C(p)} \frac{p}{p - t_i^* a} \left[- t_i^* \frac{\partial z_1^s}{\partial t} - t_i^* \frac{(1-a)}{p} z_1^d \right] - \frac{\partial f_i}{\partial P} \left[\Gamma(\theta) g'(z_1^s) \frac{\partial z_1^s}{\partial p} \right] = 0 \qquad (52)$$

This implicitly leads to the preference function $t_i^*(\theta)$. (See appendix 3.A.4 for more details.)

(2003).

[39] They also specify that for some income groups, this relation is sometimes positive.

[40] However the sign ambiguous for the middle-income voters.

[41] Subject to water-borne disease, 1600 citizens are surveyed to know how much they would pay for a universal access to water service in the home. The average WTP is more than US$6 per month. But among the sample, 79 households declared zero WTP. One of the main differences between these households and those who are willing to pay a positive amount is that those who are not willing to pay are less likely to buy water outside the home.

The tariff increases the price of good 1 and then shifts the production towards the clean good. The preferred tariff level is selected where the drop in exposure is equal to the loss of consumption utility associated to a smaller tariff revenue and a variation of the purchasing power ensued from a higher price.

Similarly to the regulation level, we are interested in finding the variation of preferred degree of openness with the individual share of income. Using (3.52) and the implicit function theorem, have

$$\frac{\partial t_i^*}{\partial \alpha_i} \lessgtr 0 \Leftrightarrow -\frac{\frac{\partial^2 V_i}{\partial t \partial \alpha_i}}{\frac{\partial^2 V_i}{\partial t^2}} \lessgtr 0. \tag{3.53}$$

as a result, if t_i^* is a maximum, we have

$$\frac{\partial t_i^*}{\partial \alpha_i} \lessgtr 0 \Leftrightarrow u_x \frac{1}{C(p)} \frac{t}{p - ta} \left[-p \frac{\partial z_1^s}{\partial t} - (1-a) z_1^d \right] (1 - \epsilon_x) \lessgtr 0 \Leftrightarrow \tag{54}$$

$$\frac{\partial t_i^*}{\partial \alpha_i} \lessgtr 0 \Leftrightarrow \epsilon_x \lessgtr 1. \tag{55}$$

(Details of the calculations are shown in appendix 3.A.5.)

The empirical literature shows that the preferred degree of trade openness tends to increase with income.[42] We shall use an assumption to this effect in what follows.

3.2.7 Effect of income on policy preferences

For both the level of regulation and the degree of trade openness, some cases will lead to corner solutions. In these situations, individual i will prefer either $\theta_i^* = 0$, $\theta_i^* = 1$, $t_i^* = 0$ or $t_i^* = t_{max}$.

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[42] See Mayda and Rodrick (2005) and Scheve and Slaughter (2001)

When the situation leads to an interior solution, it is interesting to analyze further conditions (3.51) and (3.55) that show how preferred policies change with income.

By the Engel aggregation, the weighted sum of the income elasticity of all goods is equal to one.[43] Therefore, when private mitigation is a luxury good, consumption is a necessary good and $\epsilon_x < 1$. Conditions (3.51) and (3.55) show that in this case, the preferred regulation and tariff levels unambiguously decrease with individual income. This leads to the following proposition:

Proposition 11 *The preferred regulation level and tariff decrease with the individual share of national income if, and only if, private mitigation is a luxury good; that is,*

$$\epsilon_x < 1 \Leftrightarrow \frac{\partial \theta_i^*}{\partial \alpha_i} < 0 \textit{ and } \frac{\partial t_i^*}{\partial \alpha_i} < 0. \tag{3.56}$$

The importance of this proposition is that it shows how the existence of private mitigation breaks the link between income and the preference over the environment. When people see an increase in their income and have the choice to reduce their exposure through public interventions or private means, this may lead to a decrease in the support for environmental policies.[44] Proposition 11 states the necessary and sufficient condition for this to occur. Note that the income elasticity of consumption good x will depend, among other things, on the pollution level, the private mitigation technology and the national income.

In the following section, we build a political arena where the different interests are driven by the existence of a luxury private mitigation good.

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[43] Therefore, $\epsilon_x \lesseqgtr 1 \Leftrightarrow \epsilon_d \gtreqless 1$.

[44] When the reduction in income ensued from the application of the preferred environmental policies is interpreted as the individual willingness to pay, it reflects that the environment is seen as a necessary good and not a luxury good. The proof is exposed in appendix 3.A.6. This suggests a theoretical answer to the question posed by Kristrom and Riera (1996).

3.3 Political equilibria

In this section, we consider three types of political regimes: the autocracy, the democracy and the subordinate governments. We also introduce the possibility of intermediate regimes. These political economies are all modeled by changing the constrained optimization problem that can be used to characterized the equilibria. In Section 3.4, we shall compare the different regimes and discuss the implication on the environment and welfare.

The population is separated into two groups: the rich r and the poor p. The first group represents a small proportion of the population. The second group is the majority where people are not necessarily poor in absolute terms but significantly poorer than in the first group.

Figure 3.5 illustrates a possible picture of the political arena we are exploring. It is based on simulations described in appendix 3.A.7. We have argued that for at least some baskets of technology the preferred level of regulation and the preferred degree of trade openness decrease with individual income. Referring to Proposition 11 , it would be characterized by the existence of a luxury private mitigation good. In this case, $\theta_r(t)$ stands to the left of $\theta_p(t)$ while $t_r(\theta)$ lies under $t_p(\theta)$. The preference functions $\theta_\imath(t)$ and $t_\imath(\theta)$ are explicitly defined in the text bellow. Because the rich can spend a larger share of their income to privately defend themselves against pollution, they prefer a lower public intervention in both policy dimensions.

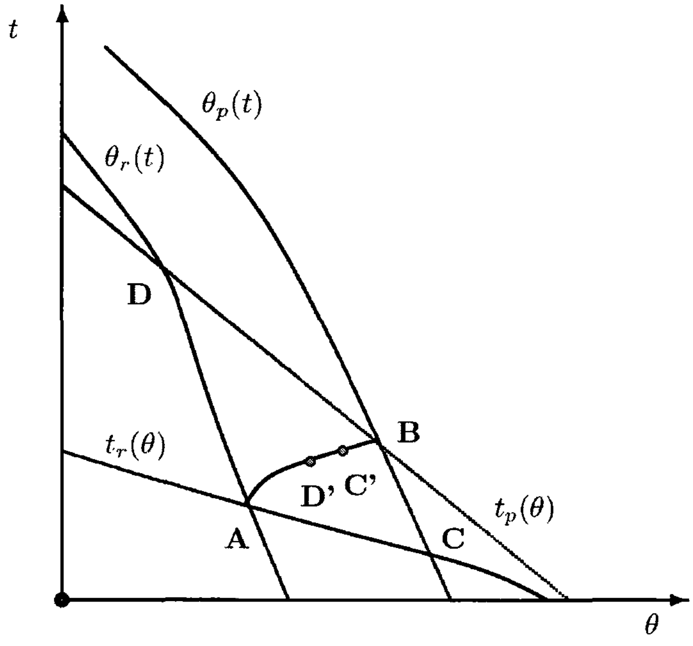

Fig. 3.5. Diagram of the political equilibrium

3.3.1 The autocratic regime

The autocratic or totalitarian regime is one in which only the rich, called the elite in this case, decide. They choose the regulation level and the tariff so as to maximize their own utility, regardless of the welfare of other citizens. The problem that describes the situation is:

$$\max_{\theta,t} V_r = ln(x_r) - f(d_r, P) \tag{57}$$

$$\text{s.t. } x_r = \frac{\alpha_r I}{C(p)} - d_r \tag{58}$$

$$\text{and equations (3.36) to (3.42) and (3.43).} \tag{59}$$

The solution can be described in the following way:

$$\hat{\theta} = \theta_r(\hat{t}) \text{ and } \hat{t} = t_r(\hat{\theta})$$

where $\theta_r(t)$ is such as $\partial V_r/\partial\theta = 0$ and $t_r(\theta)$ is such as $\partial V_r/\partial t = 0$. On the graph this equilibrium is shown as the point of intersection of the two functions (point A).

3.3.2 The democratic regime

In a fully competitive democracy, the choice of problems can be characterized as those that solve the synthetic optimization problem of maximizing political support, using a particular weighted sum of utilities, subject to the structure of the economy.[45] The opinion of everyone counts in proportion to their respective influence. In the present context, this problem is:

$$\max_{\theta,t} U = \sum^{r}(1-\gamma)V_r + \sum^{p}\gamma V_p \tag{60}$$

$$\text{s.t. equations (3.36) to (3.42) and (3.43)} \tag{61}$$

where $0 < \gamma < 1$ is the influence of a poor individual.[46]

In order to represent democracy graphically, we must first find the poor's preferred equilibrium. It is characterized by the following optimization problem:

$$\max_{\theta,t} V_p = ln(x_p) - f(d_p, P) \tag{63}$$

$$\text{s.t. } x_p = \frac{\alpha_p I}{C(p)} - d_p \tag{64}$$

$$\text{and equations (3.36) to (3.42) and (3.43).} \tag{65}$$

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[45] For references see Hettich and Winer (1999), Coughlin (1992) and Coughlin and Nitzan (1981).

[46] When the government maximizes its expected votes (EV), it maximizes the following function:

$$\max_{\theta,t} EV = \sum^{i}\pi_i = \sum^{i}\pi[V_i(\theta,t) - V_i(\theta_o,t_o)]. \tag{62}$$

which is the sum of the probability of voting of each individual while this individual compares the government's proposition and the one of its opponent (subscript o). In this case, the weighed factor is the sensitivity to a change in the individual welfare in equilibrium $\gamma_i = \partial\pi_i/\partial V_i$.

The solution is defined in the following way:

$$\tilde{\theta} = \theta_p(\tilde{t}) \text{ and } \tilde{t} = t_p(\tilde{\theta})$$

where $\theta_p(t)$ is such that $\partial V_p/\partial\theta = 0$ and $t_p(\theta)$ is such as $\partial V_p/\partial t = 0$. The preferred policy mix for the poor is described by point B, where the two preference curves meet, as shown in Figure 3.5. By (3.60), the democratic equilibrium can be anywhere along the segment AB.[47]

3.3.3 The subordinate regimes

The third and fourth equilibria represent a society where each group decides on one political dimension only. It is modeled as a Nash game where the elite are decisive with respect to the level of regulation or with respect to the degree of trade openness. Simultaneously, the poor are decisive with respect to the other policy dimension.

The first case is the one where the rich, or the elite, are decisive with respect to trade openness while the population controls environmental regulation.

The optimization problem of the rich group is defined as:

$$\max_t V_r = ln(x_r) - f(d_r, P) \tag{66}$$

$$\text{s.t. } x_r = \frac{\alpha_r I}{C(p)} - d_r \tag{67}$$

$$\text{and equations (3.36) to (3.42) and (3.43),} \tag{68}$$

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[47] In a democratic regime, the equilibrium cannot be at A or at B, otherwise a vote cycle emerge. See Hettich and Winer (1999).

while the poor group behavior is:

$$\max_{\theta} V_p = ln(x_p) - f(d_p, P) \tag{69}$$

$$\text{s.t. } x_p = \frac{\alpha_p I}{C(p)} - d_p \tag{70}$$

$$\text{and equations (3.36) to (3.42) and (3.43).} \tag{71}$$

The equilibrium is defined by the following:

$$\bar{\theta} = \theta_p(\bar{t}) \text{ and } \bar{t} = t_r(\bar{\theta}),$$

This third equilibrium is then the point of intersection between the rich's preferred tariff function and the poor's preferred regulation level function. It is illustrated by point C in Figure 3.5 .

This equilibrium represents the case where trade openness is really important to the elite. Therefore they have to grant a large level of regulation to the population in order to keep their political support. To illustrate this, we could think of the 2007 referendum in Costa Rica where the government consulted the population about the Central American Free Trade Agreement. Having relatively good social protection, people were concerned about the possibility of losing this advantage after the implementation of a higher trade flow and stronger international competition. Rich partisans of free trade who wanted first a low level of social services had then to accept a high social protection to finally win the referendum with 51.5% of the votes.

However, one could tell a similar story in a different manner where the elite are decisive with respect to the level of regulation and the rest of the population controls the tariff. This last equilibrium is the point D in Figure 3.5 and is defined by:

$$\dot{\theta} = \theta_r(\dot{t}) \text{ and } \dot{t} = t_p(\dot{\theta}).$$

3.3.4 Intermediate regimes

The optimization problem that describes democracy in section 3.3.2 imposes that both groups are equally influential in both dimensions. Hence, if the poor are highly influential in trade decisions, they must also be highly influential in the control of regulation. Conversely, in the subordinate cases, the entire influence over each dimension is allocated to one of the groups. In the spectrum of all possible regimes, it is reasonable to think that some of them could lie between the perfect democracy and the subordinate regimes. This will occur when the influence of each group varies with the policy dimension. Because of historical and institutional factors, each group can develop tools and networks such as unions, social protection or trade agreements. They are then better prepared to fight over one dimension than in the other and they choose slightly different battlefields.

The preference functions are then the results of a democratic process where the political equilibrium level of environmental regulation $\theta_\gamma(t)$ is:

$$\max_{\theta} U = \sum^{r}(1-\gamma_\theta)V_r + \sum^{p}\gamma_\theta V_p \tag{72}$$

$$\text{s.t. equations (3.36) to (3.42) and (3.43)} \tag{73}$$

while the democratic degree of trade openness $t_\gamma(\theta)$ is the outcome of the following optimization:

$$\max_t U = \sum^r (1-\gamma_t)V_r + \sum^p \gamma_t V_p \tag{74}$$

$$\text{s.t. equations (3.36) to (3.42) and (3.43).} \tag{75}$$

The parameters $\gamma_\theta \in [0,1]$ and $\gamma_t \in [0,1]$ are the weighed factors of poor citizens in dimensions θ and t and represent their influence in controlling the respective policy outcome. When the two functions are combined, the political equilibrium is:

$$\ddot{\theta} = \theta_\gamma(\ddot{t}) \text{ and } \ddot{t} = t_\gamma(\ddot{\theta}).$$

Using all possible combinations of $\gamma_\theta \in [0,1]$ and $\gamma_t \in [0,1]$, this equilibrium maps out the whole surface within the four points A, B, C and D and the four lines that link them together. When $0 < \gamma_\theta = \gamma_t = \gamma < 1$, the political equilibrium is on the line $\overline{AB}$ and when $\gamma_\theta = \gamma_t = 0$ (i.e. the poor have no influence in both dimensions), we find back the authoritarian equilibrium. The subordinate regimes are characterized by $\gamma_\theta = 1$ and $\gamma_t = 0$ (point C) or by $\gamma_\theta = 0$ and $\gamma_t = 1$ (point D).

Therefore the example of Costa Rica discussed in section 3.3.3 would lie in triangle ABC, where $\gamma_\theta > \gamma_t$. Costa Rica is a democracy and the opinions of each group influence every political decision. However, when the high spheres of the government bring the question of trade openness to the population, the later answers with the issue of social protection. This shows the preference of each group for one policy dimension ($\gamma_\theta \neq \gamma_t$).

Although they present different characteristics, democracies and more dictatorial regimes cannot be separated in a perfectly dichotomous way. The area ABCD delineates all the shades that can take such political regimes.

3.4 So, is democracy good for the environment?

In the present section, the environmental effects associated with the political outcome of the different regimes are compared in order to determine which one is likely to give the most environmentally friendly policies. The conclusions are based on a simulated economy which exemplifies a possible particular case illustrated in Figure 3.5. The functional functions and parameter values are defined in appendix 3.A.7.

In order to declare that one equilibrium is more eco-friendly than another, it is possible to refer to two different criteria. The first one observes only the stringency of the environmental regulation. The larger is the regulation, the cleaner is the technology used in the dirty industry and the more environmentally friendly is the economy. The second criterion reflects the effects of both trade openness and regulation by looking at the local pollution emission. The less an economy pollutes, the better it is.[48]

A third criterion is also analyzed in this section. It is the welfare of both groups. Leaving aside the objectives on environmental quality, it suggests that some equilibria are preferred and maybe more likely to happen than others.

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[48] Although this last criterion excludes the possible effects of emission delocalization on global pollution. The two criteria are used in political discussions although their implications are different. During the last pre-electoral period in Canada (October 2008), the conservative environmental program exposed mostly regulations per unit of output (θ) while the liberal party proposed reduction in the total emissions (P). The objectives of the Kyoto protocol also make use of the second criterion.

3.4.1 Comparison of the equilibria with respect to the level of regulation θ

A look at Figure 3.5 is sufficient to rank order the political equilibria with respect to the level of regulation. This leads to the following proposition:

Proposition 12 *The four equilibria are rank ordered with respect to θ in the following way:*

$$C \succ B \succ A \succ D. \tag{3.76}$$

In terms of environmental regulation, democracy ($\overline{AB}$) does better than autocracy (A) but lies between the two subordinate cases (C and D). This proposition is rather surprising because it shows that in particular contexts subordinate regimes can lead to higher environmental standards than any democratic regime.[49] When the elite control the tariff and a high degree of trade openness is very important to them, they have to compromise by offering tighter environmental regulations.

3.4.2 With respect to the level of pollution P

Remembering that the level of pollution P varies negatively with the level of regulation as well as with the degree of trade openness, it is straightforward to see that democracy is less polluting than autocracy. However, Figure 3.5 does not permit further conclusions. Using simulations and the political outcome of each regime, it is possible to rank order

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[49] In a general equilibrium framework, this last statement holds if the poor see protectionist measures t as substitutes for environmental regulation θ. With this assumption, $\theta_p(t)$ and $t_p(\theta)$ show negative slopes and point C always lies at the right of $\overline{AB}$.

the four points with respect to the level of pollution generated. This leads to the following observation:

Proposition 13 *The four equilibria are rank ordered with respect to* P *in the following way:*

$$B \succ C \succ D \succ A. \tag{3.77}$$

In Figure 3.5, the points C' and D' represent the democratic equilibria that give respectively the same levels of pollution than those generated by C and D. Therefore, when the poor are highly represented in a democratic regime, the democratic equilibrium is towards point B and is more eco-friendly than the subordinate regimes. When the rich are more weighted, the equilibrium is closer to point A and the subordinate regimes may be less polluting.

Proposition 14 *The more the poor are weighted in the democratic regime, the more likely it is that democracy generates less pollution than subordinate governments.*

3.4.3 With respect to welfare V_r and V_p

With the simulated economy, it is also possible to rank order the outcomes with respect to the equilibrium utility of the rich and the poor:

Proposition 15 *The four equilibria are rank ordered with respect to* V_r *in the following way:*

$$A \succ D \succ C \succ B, \tag{3.78}$$

and with respect to V_p:

$$B \succ C \succ A \succ D. \tag{3.79}$$

In this particular situation, the autocratic regime pareto-dominates the subordinate government when the elite is decisive with respect to the level of regulation (point D). In a static setting, we would expect to see the poor group voluntarily give up their influence on the trade dimension in order to have the political outcome at point A where both groups reach a higher utility.

For both groups the other subordinate case (point C) comes in the middle of the democratic possibilities (between A and B). Therefore rich and poor will prefer this subordinate regime over a democratic outcome where the other group is highly weighted.

These observations, when exposed in parallel to the example of Costa Rica, suggest that in a dynamic framework, a democratic government would naturally tend to diverge towards one of the subordinate regimes. Each group has a comparative advantage in defending their interests on one dimension. Institutions evolve then in that direction and influence asymmetries become noticeable. France is another eloquent example. On one side, they have untouchable workers rights (for instance, the 35 hour week or the 5 weeks of vacation) that haven't loosened with the increasing competition of the European Union. On the other side, their implication in the European Community responds to the desire of a specific group and, somehow, overpasses the opinion of the population who voted “no" to the 2005 referendum.

In the present case, an institutional dynamic that pulls the equilibrium towards point C corresponds to stricter environmental regulation, although it steps away from perfect democracy.

3.5 Conclusion

The present theoretical model explores the direct link between democracy and the environment in the context of a small open economy. Inequality in income and the inclusion of private mitigation have far reaching consequences. While richer citizens prefer the use of private defence against pollution and the higher income that comes with an unregulated economy, poorer individuals may prefer public interventions in order to reduce their exposure. Income inequality, whatever its source, causes divergence of interests through the existence of private mitigation. This scenario occurs particularly when the existing technology and the cost of private mitigation bring a consumption pattern that characterizes the later as a luxury good.

In the political arena, the different income groups express simultaneously their preferences over the two policy dimensions: the level of environmental regulation and the degree of trade openness. This multi-dimensional political setting allows for an important feature: the possibility of a variation in the influence of each group with the policy dimension. The manipulation of these parameters as the mirror of historical and institutional aspects allows to explore all the political regimes from the autocracy to the fully competitive democracy, in passing by the subordinate regimes. Each regime can be modeled as a constrained optimization problem that characterizes the equilibrium.

As the result of the comparison between the political outcomes, we show how the subordinate elite can trade off tight regulations against a high level of trade, a political outcome that lies outside of the democratic area and that is qualified as environmentally friendly. We can also compare the regimes with respect to the level of pollution generated. Although democracy is less polluting than autocracy, our simulated economy shows that when the rich are highly weighted in a democracy, subordinate regimes are more likely to do better. Finally, institutional dynamics may also lead to outcomes more eco-friendly than fully democratic equilibria.

So, is democracy good for the environment? By the light of this analysis, it is not clear that democracy always leads to the best environmental protection.

3.A Appendix

3.A.1 The second order conditions in the choice of d_i^*

$$\frac{\partial^2 V_i}{\partial d_i^2} = -\frac{1}{x_i^2} - \frac{\partial^2 f(d_i^*, P)}{\partial d_i^2} < 0 \tag{3.80}$$

3.A.2 The preferred regulation level θ_i^*

$$\frac{\partial V_i}{\partial \theta} = 0 \Rightarrow u_x(x_i^*)\frac{\partial x_i^*}{\partial \theta} - \frac{\partial f(d_i^*,P)}{\partial d}\frac{\partial d_i^*}{\partial \theta} - \frac{\partial f(d_i^*,P)}{\partial P}\frac{\partial P}{\partial \theta}$$

We know from the budget constraint that $\frac{\partial x_i^*}{\partial \theta} = \frac{\alpha_i}{C(p)} \frac{\partial I}{\partial \theta} - \frac{\partial d_i^*}{\partial \theta}$. We also know from the FOC for the optimal choice of d that $u_x(x_i^*) = -\partial f(d_i^*, P)/\partial d$. Then we have:

$$u_x \frac{\alpha_i}{C(p)} \frac{\partial I}{\partial \theta} - \frac{\partial f_i}{\partial P} \left[\Gamma(\theta_i^*) g'(z_1^s) \frac{\partial z_1^s}{\partial \theta} + \Gamma'(\theta_i^*) g(z_1^s) \right] = 0 \Rightarrow$$

$$u_x \frac{\alpha_i}{C(p)} \frac{p}{p-ta} \left[\underbrace{(p^* + (1-\theta) g'(z_1^s))}_{=-t} \frac{\partial z_1^s}{\partial \theta} - g(z_1^s) \right]$$

$$- \frac{\partial f_i}{\partial P} \left[\Gamma(\theta_i^*) g'(z_1^s) \frac{\partial z_1^s}{\partial \theta} + \Gamma'(\theta_i^*) g(z_1^s) \right] = 0 \Rightarrow$$

$$\frac{1}{x_i^*} \frac{\alpha_i}{C(p)} \frac{p}{p-ta} \left[-t \frac{\partial z_1^s}{\partial \theta} - g(z_1^s) \right] - \frac{\partial f_i}{\partial P} \left[\Gamma(\theta_i^*) g'(z_1^s) \frac{\partial z_1^s}{\partial \theta} + \Gamma'(\theta_i^*) g(z_1^s) \right] = 0$$

And the second order condition is:

$$\frac{\partial^2 V_i}{\partial \theta^2} =$$

$$u_{xx} \frac{\partial x_i^*}{\partial \theta} \frac{\alpha_i}{C(p)} \frac{p}{p-ta} \left[-t \frac{\partial z_1^s}{\partial \theta} - g(z_1^s) \right] + u_x \frac{\alpha_i}{C(p)} \frac{p}{p-ta} \left[-t \frac{\partial^2 z_1^s}{\partial \theta^2} - g'(z_1^s) \frac{\partial z_1^s}{\partial \theta} \right]$$

$$- \frac{\partial^2 f_i}{\partial P^2} \left(\frac{\partial P}{\partial \theta} \right)^2 - \frac{\partial f_i}{\partial P} \frac{\partial^2 P}{\partial \theta^2}$$

3.A.3 The variation of θ_i^* with respect to α_i

$$\frac{\partial^2 V_i}{\partial \theta \partial \alpha_i} = \frac{u_x}{C(p)} \frac{p}{p-ta} \left[-t \frac{\partial z_1^s}{\partial \theta} - g(z_1^s) \right] + \frac{\alpha_i}{C(p)} u_{xx} \frac{\partial x_i^*}{\partial \alpha_i} \frac{p}{p-ta} \left[-t \frac{\partial z_1^s}{\partial \theta} - g(z_1^s) \right]$$

We multiply the middle term per $(-1/-1)$, (x_i/x_i) and (u_x/u_x) and we get

$$\frac{u_x}{C(p)} \frac{p}{p-ta} \left[-t \frac{\partial z_1^s}{\partial \theta} - g(z_1^s) \right] - \underbrace{\frac{\alpha_i}{x_i} \frac{\partial x_i^*}{\partial \alpha_i}}_{=\epsilon_x} \underbrace{\left(-\frac{u_{xx} x_i}{u_x} \right)}_{=\sigma=1} \frac{u_x}{C(p)} \frac{p}{p-ta} \left[-t \frac{\partial z_1^s}{\partial \theta} - g(z_1^s) \right] \Leftrightarrow$$

$$\frac{u_x}{C(p)} \frac{p}{p-ta} \left[-t \frac{\partial z_1^s}{\partial \theta} - g(z_1^s) \right] (1 - \epsilon_x).$$

Here, σ is the curvature of the utility function. Due to the logarithmic form, it is equal to one.

3.A.4 The preferred degree of trade openness t_i^*

Using similar manipulations as in appendix 3.A.2 we have:

$$\frac{\partial V_i}{\partial t} = 0 \Leftrightarrow u_x \frac{\partial x_i^*}{\partial t} - \frac{\partial f_i}{\partial P}\left[\Gamma(\theta) g'(z_1^s)\frac{\partial z_1^s}{\partial p}\right] = 0$$

$$\text{where } \frac{\partial x_i^*}{\partial t} = \frac{\alpha_i}{C(p)}\frac{\partial I}{\partial t} - \underbrace{\frac{C'(p)\alpha_i I}{C(p)^2}}_{=\frac{z_1^d \alpha_i}{C(p)}}$$

$$\text{and } \frac{\partial I}{\partial t} = \frac{p}{p-ta}\left[\underbrace{(p^* + (1-\theta)g'(z_1^s))}_{=-t}\frac{\partial z_1^s}{\partial t}\right] + (p^* z_1^s + (1-\theta)g(z_1^s))\left[\frac{p}{p-ta}\frac{a}{p}\frac{p^*}{p-ta}\right] =$$

$$\frac{p}{p-ta}\left[-t\frac{\partial z_1^s}{\partial t}\right] + z_1^d \frac{p-t}{p-ta} \Leftrightarrow$$

$$u_x \frac{\alpha_i}{C(p)}\frac{p}{p-ta}\left[-t\frac{\partial z_1^s}{\partial t} - t\frac{(1-a)}{p} z_1^d\right] - \frac{\partial f_i}{\partial P}\left[\Gamma(\theta) g'(z_1^s)\frac{\partial z_1^s}{\partial p}\right] = 0$$

And the second order condition is:

$$\frac{\partial^2 V_i}{\partial t^2} =$$

$$u_{xx}\frac{\partial x_i^*}{\partial t}\frac{\alpha_i}{C(p)}\frac{t}{p-ta}\left[-p\frac{\partial z_1^s}{\partial t} - (1-a)z_1^d\right] + u_x \alpha_i \left[\frac{1}{C(p)}\frac{p-t}{(p-ta)^2} - \frac{C'(p)}{C(p)^2}\frac{t}{p-ta}\right]\left[-p\frac{\partial z_1^s}{\partial t} - (1-a)z_1^d\right]$$

$$+ u_x \frac{\alpha_i}{C(p)}\frac{t}{p-ta}\left[\frac{\partial z_1^s}{\partial t} - p\frac{\partial^2 z_1^s}{\partial t^2} - (1-a)\frac{\partial z_1^d}{\partial t}\right] - \frac{\partial^2 f_i}{\partial P^2}\left(\frac{\partial P}{\partial t}\right)^2 - \frac{\partial f_i}{\partial P}\frac{\partial^2 P}{\partial t^2}$$

3.A.5 Variation of t_i^* with respect to α_i

Using the same manipulations as in appendix 3.A.3, we get:

$$\frac{\partial^2 V_i}{\partial t \partial \alpha_i} \lesseqgtr 0 \Leftrightarrow u_x \frac{1}{C(p)}\frac{t}{p-ta}\left[-p\frac{\partial z_1^s}{\partial t} - (1-a)z_1^d\right](1-\epsilon_x) \lesseqgtr 0$$

3.A.6 WTP for environmental policies

Considering the WTP as the individual opportunity cost of $\theta_\imath^*$, we have .

$$WTP = -\alpha_\imath \int_0^{\theta_\imath^*} \frac{\partial I}{\partial \theta} \partial \theta = \alpha_\imath [I(\theta)]_{\theta_\imath^*}^{0}$$

And then

$$\frac{\partial (WTP/\alpha_\imath I)}{\partial \alpha_\imath} = -\frac{1}{I} \underbrace{\frac{\partial I}{\partial \theta}}_{<0} \frac{\partial \theta_\imath^*}{\partial \alpha_\imath}$$

Then $\frac{\partial (WTP/\alpha_\imath I)}{\partial \alpha_\imath}$ and $\frac{\partial \theta_\imath^*}{\partial \alpha_\imath}$ have the same sign and

$$\frac{\partial (WTP/\alpha_\imath I)}{\partial \alpha_\imath} \lesseqgtr 0 \Leftrightarrow \epsilon_\theta \lesseqgtr 1 \Leftrightarrow \frac{\partial \theta_\imath^*}{\partial \alpha_\imath} \lesseqgtr 0 \Leftrightarrow \epsilon_x \lesseqgtr 1$$

Using similar manipulation for the opportunity cost of t we have:

$$\epsilon_\theta \lesseqgtr 1 \Leftrightarrow \epsilon_t \lesseqgtr 1 \Leftrightarrow \epsilon_x \lesseqgtr 1$$

3.A.7 Simulation

Equations take the functional forms:

$$V_\imath = \ln(x_\imath) - (P - \delta\sqrt{d_\imath}),$$

where $P - \delta\sqrt{d_\imath} \geq 0$,

$$g(z_1^s) = (b - (z_1^s)^2) \Rightarrow z_2^s = (1-\theta)(b - (z_1^s)^2),$$

$$\Gamma(\theta) = (1-\theta) \Rightarrow P = (1-\theta)^2(b - (z_1^s)^2),$$

where b is the total factor endowment while δ describes the technology of private mitigation. Parameters take the following values:

$$p^* = 0.4,$$

$$a = 0.5,$$

$$\delta = 3,$$

$$\alpha_r = 0.4,$$

$$\alpha_p = 0.1,$$

$$b = 5.$$

Note that a rich individual is 40 times richer than a poor individual. The whole population could than be 1 rich person and 60 poor people so to respect the condition $\sum_{i=1}^{n} \alpha_i = 1$.

Conclusion

This thesis explores three different questions on environmental economics. The two first chapters, *Remanufacturing* and *Transboundary movements of waste*, investigate topics related to products' end-of-life. The last chapter, *Is democracy good for the environment? The role of private mitigation efforts*, builds a political arena where is observed the impact of different political regimes on the environment.

In *Remanufacturing* is developed a model where a duopoly of original manufacturers compete for the production of a new good. They also have to select the level of remanufacturability of their products, a technological choice that defines the ease with which a product at the end of its life can be refurbished and sold again. However, an increased level of remanufacturability attracts independent competitors in the remanufacturing industry. In this model, the application of a regulation promoting remanufacturable technology is studied.

The main result shows that the introduction of an environmental regulation can increase profits in the regulated industry. This result corroborates the Porter Hypothesis. Other results say that a social planner could use collusion on the level of remanufacturability as a substitute for an environmental regulation since it leads to higher levels of remanufacturability. However, the social planner who wants to implement an environmental regulation would have better support if the firms do not collude.

The second chapter, *Transboundary movements of waste,* considers a North-South model where used durable goods in the North are imported by the firm in the South as an input to production. The lack of international vigilance allows for illegal waste to be mixed with reusable products.

The main result explains how extended producer responsibility programs, which makes producers responsible for the cost of waste disposal, combined with large differences in local waste regulation between the two countries open up the valve to illegal shipments of waste. This result is in line with the Pollution Haven Hypothesis, which says that differences in environmental regulations between rich and poor countries lead to a delocalization of pollution towards developing countries. Also, the model suggests that under particular scenarios, increasing international vigilance can lower the purity of exported goods and increase illegal shipments of waste.

The last chapter, *Is democracy good for the environment? The role of private mitigation efforts*, coauthored with Louis Hotte and Stanley L. Winer, explores the environment-trade-democracy nexus. In a theoretical framework, the assumption is made that through private mitigation against pollution, income inequality leads to divergence of political preferences over two political dimensions, i.e. an environmental regulation and openness to trade. Four political regimes are studied: democracy, a totalitarian regime and two subordinate regimes.

Results say that subordinate regimes can be more eco-friendly than any democratic regimes. This occurs when the elite imposes a high degree of openness to trade and compensate by according a high level of environmental regulation. Other results suggest that the more the rich are weighted in a competitive democracy, the more likely it is that subordinate regimes pollute less than democracy.

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