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Three problems in the market of a green product : fiscal avoidance, signal, and vertical differentiation

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**THÈSE POUR OBTENIR LE GRADE DE DOCTEUR
DE L'UNIVERSITÉ DE MONTPELLIER**

EN ÉCONOMIE - SECTION CNU 05
ÉCOLE DOCTORALE EDEG
UNITÉ DE RECHERCHE LAMETA

**TROIS PROBLÈMES SUR LE MARCHÉ
D'UN PRODUIT VERT :**

**ÉVITEMENT FISCAL, SIGNAL & DIFFÉRENCIATION
VERTICALE**

PRÉSENTÉE PAR MARIA N. CHISTYAKOVA

LE 30 NOVEMBRE 2017

SOUS LA DIRECTION DE PR. PHILIPPE MAHENC

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**UNIVERSITÉ
DE MONTPELLIER**

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FROM THE UNIVERSITY OF MONTPELLIER**

ECONOMICS - SECTION 05 CNU
EDEG DOCTORAL SCHOOL
LAMETA RESEARCH UNIT

**THREE PROBLEMS IN THE MARKET OF
A GREEN PRODUCT:
FISCAL AVOIDANCE, SIGNAL & VERTICAL
DIFFERENTIATION**

PRESENTED BY MARIA N. CHISTYAKOVA

NOVEMBER 30, 2017

UNDER THE SUPERVISION OF PR. PHILIPPE MAHENC

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Résumés de la thèse

Résumé en français

La qualité environnementale ayant des caractéristiques d'un bien public fait objet de cette thèse. Dans un cadre théorique, on étudie d'abord les moyens de régulation d'une entreprise polluante et ensuite le choix décentralisé de la qualité environnementale. Pour une entreprise capable d'esquiver le fisc, la conformité à la taxation est déterminée en fonction du niveau de la taxe. Lorsque elle augmente, la non-conformité devient plus attractive. L'échappement fiscal modifie la composition de la taxe : elle prend en compte l'effet d'un comportement de passager clandestin de la firme et l'effet de l'érosion de l'assiette fiscale. La taxe optimale du second rang doit équilibrer ces deux effets opposés. Le comportement de passager clandestin rend le régulateur soit impuissant, soit inéquitable en fonction de la sévérité du dommage environnemental et de l'efficacité de l'entreprise. Dans un second temps, on étudie l'impact de la taxe environnementale sur la politique de prix d'un monopole qui utilise le signal en prix afin de communiquer aux consommateurs le haut niveau de qualité environnementale inobservable. On applique deux critères de sélection de l'équilibre : le critère intuitif et le critère d'invincibilité. L'asymétrie d'information place le niveau de la taxe au-dessous du niveau Pigouvien ajusté selon l'exercice du pouvoir du marché. En cas de sélection par le critère d'invincibilité la taxe peut basculer un équilibre séparateur dans un équilibre mélangeant ce qui rétablit le problème d'asymétrie d'information. Enfin, on montre que le choix de qualité environnementale de la part de l'entreprise est sous-optimale même si elle internalise le dommage environnemental.

Mots-clés : qualité environnementale, régulation, pouvoir du marché, évitement fiscal, information incomplète, choix de la qualité

Abstract

Environmental quality having features of a public good is the subject of the thesis. In a theoretical framework, we study a means of environmental regulation of a polluting firm endowed with market power and then determine the optimal decentralized choice of environmental quality. We start with examining how tax avoidance affects the optimal second-best tax on polluting emissions in a monopoly setting. The firm is owned by shareholders who differ in their cost of tax dodging. The optimal tax should correct two negative externalities of avoidance: the firm's free-riding effect and a tax base erosion effect. This free-riding makes the regulator either impotent or unfair, depending on the severity of the environmental damage and the firm's efficiency. Next, we analyze the impact of an environmental tax on the signaling price strategy of a monopoly that communicates to consumers the unobservable information about firm's high environmental performance. We use the intuitive and undefeated criteria of equilibrium selection. Asymmetric information places the optimal second-best tax below the level required under complete information. In the case of undefeated equilibria selection, the tax may induce a 'migration' from separating equilibrium to pooling making the firm prefer to conceal the private information about environmental quality. Finally, we show that market choice of environmental quality by a firm that internalizes environmental damage from polluting emissions is yet suboptimal.

Keywords: environmental quality, regulation, market power, fiscal avoidance, incomplete information, quality choice

Introduction Générale

Alors que la notion générale de qualité a évolué depuis des décennies voire même des siècles pour certains produits comme le vin et le fromage français, le phénomène de qualité environnementale est quant à lui relativement récent. Il s'est concrétisé avec la production de masse, générant la préoccupation d'une haute performance financière tout en négligeant l'impact sur l'environnement.

Les normes de qualité environnementale sont en train de rentrer dans les cahiers des charges pour une grande gamme des produits. Etant devenue une qualité centrale et stratégique d'un produit, la qualité environnementale concerne l'intérêt de chaque acteur du marché. Les consommateurs expriment leur intérêt (de plus en plus) pour la qualité environnementale, les entreprises cherchent à répondre aux attentes des consommateurs, quant au régulateur, il veille sur les défaillances du marché. Dans la tendance générale de mondialisation et de dérégulations, les organisations non-gouvernementales (ONGs) commencent à avoir une position particulière dans le rapport de forces en faisant le lien entre tous les acteurs du marché et en comblant les lacunes de l'intérêt public.

Ces interactions entre les acteurs du marché et la préoccupation avec des problèmes environnementaux mènent, entre autres, au changement de politique publique.

Dans un premier temps, on s'interroge donc sur l'impact d'une taxation environnementale sur le comportement de l'entreprise vis-à-vis du régulateur et/ou du fisc. On considère que la gérance de l'entreprise est confiée aux exécutifs qui cherchent à maximiser la performance financière de la firme. Cette ambition généreusement récompensée se voit menacée par la taxe permettant l'incitation aux exécutifs à réduire la charge financière imposée par la politique environnementale.

Le chapitre 1 étudie l'impact de l'évitement fiscal sur la taxation optimale de second rang portant sur les émissions polluantes d'un monopole. L'entreprise est détenue par des actionnaires hétérogènes dans leur capacité d'esquiver le fisc. La conformité de l'entreprise à la taxation environnementale est déterminée en fonction des coûts

d'évitement. Elle dépend du niveau de la taxe. Lorsque la taxe augmente, la non-conformité devient attractive pour un plus grand nombre d'actionnaires. Dans la tradition de Buchanan (1969), la taxe optimale devrait corriger les deux externalités négatives qui proviennent de la pollution et du comportement en situation de monopole. La capacité à échapper le fisc introduit un nouveau paramètre de décision. L'analyse fait apparaître de deux effets opposés de l'évitement fiscal sur le design de la politique environnementale : l'effet d'un comportement de passager clandestin des actionnaires et l'effet de l'érosion de l'assiette fiscale suite à une hausse de taxe. Le mécanisme que la taxe déclenche est le suivant : lorsque la non-conformité augmente, le niveau de la taxe doit aussi augmenter, ce qui entraîne, par conséquent, encore plus d'esquive. Etant donnée l'hétérogénéité des actionnaires face à l'évitement fiscal, le régulateur doit internaliser l'externalité imposée par le comportement de passager clandestin de l'entreprise sur le reste de la société. La taxe optimale doit équilibrer ces deux effets opposés. Le comportement de passager clandestin rend le régulateur soit impuissant, soit inéquitable en fonction de la sévérité du dommage environnemental et de l'efficacité de l'entreprise. Dans le cadre d'un dommage modéré où la taxation à la Buchanan aurait été instaurée, le régulateur s'abstient de la régulation car la perte des contribuables serait plus coûteuse pour la société que le gain de correction de l'externalité environnementale. Pour un dommage considérable, la taxe doit dépasser le niveau de Buchanan. En conclusion, quand la politique environnementale est mise en place, les consommateurs en supportent le fardeau financier. Dans le cas contraire, ils supportent la pollution. Nous démontrons par ailleurs qu'un programme d'une taxe à deux parties peut atteindre la solution du premier rang.

A part d'une réponse comportementale de l'esquive fiscale, la taxation environnementale peut aussi entraîner une réponse stratégique de part de l'entreprise. Cela fait l'objet du chapitre 2. Motivée par une prime sur la haute qualité environnementale, l'entreprise propre a l'intérêt à transmettre crédiblement l'information sur la qualité de son produit afin de bénéficier du consentement de part des consommateurs à payer plus pour une

haute qualité environnementale. En même temps, l'entreprise polluante peut exploiter ces espérances des consommateurs en imitant la haute qualité. Le chapitre 2 est dédié à l'analyse des actions stratégiques de la firme face aux problèmes d'information incomplète.

Le chapitre 2 étudie l'impact de l'asymétrie d'information sur la taxe environnementale du second rang. L'intérêt principal du chapitre est d'endogénéiser la taxe afin d'évaluer son impact sur le bien-être social. Le cadre comprend un cas d'industrie en concurrence imparfaite et une qualité environnementale inobservable. Un monopole utilise le prix pour signaler que son produit propre (qualité haute) ne génère pas de pollution. Pour éviter qu'un producteur de type sale (qualité faible) ne vende un produit polluant au même prix que le produit propre, le monopole doit distordre le prix du produit propre relativement au niveau d'information complète.

On distingue deux formes de régulation lorsque l'équilibre sépare les deux types : (i) la régulation faible qui préserve l'avantage en coûts du monopole sale; (ii) la régulation forte qui donne l'avantage en coûts au monopole propre.

Le niveau de la taxe optimale doit être inférieur au niveau imposé en cas de monopole polluant avec information complète. La taxe comprend trois éléments correspondant aux externalités présentes sur le marché. En partant d'un niveau Pigouvien équivalent au dommage marginal, la taxe est ajustée selon le comportement du monopole qui restreint la production afin d'obtenir une rente non-compétitive. De plus, ce niveau est réduit encore pour prendre en compte l'impact de l'asymétrie d'information.

Puisque la taxe s'infiltré dans le prix du produit propre, que ce soit un équilibre séparable ou mélangeant, l'espérance des consommateurs d'une haute qualité environnementale augmente l'importance que le régulateur attribue au produit propre. Cela entraîne la baisse de sévérité de la taxe environnementale relativement à la situation d'information complète.

En outre, sous un équilibre séparable, la taxe ne peut plus égaliser la valeur sociale espérée d'un produit à son coût social espéré. Pour une régulation faible, en moyenne le

prix doit être supérieur au coût social, cette relation s'inverse dans le cas d'une régulation forte. Car l'information incomplète oblige le monopole propre à distordre son prix, la réaction du prix au changement de la taxe dépend de la position relative du prix du produit propre par rapport au niveau qui maximise le profit.

L'analyse de bien-être donne les résultats suivants : la régulation environnementale réduit le profit du monopole polluant qu'il y ait ou non séparation des types. La régulation environnementale augmente le profit du monopole propre dans le cas d'une régulation forte et dans le cas d'un équilibre mélangeant. Or, le bien-être des consommateurs du produit propre est en général réduit suite à la régulation environnementale.

Dernièrement, on s'intéresse au choix optimal de qualité environnementale de part de l'entreprise et du régulateur. Ces choix ne peuvent pas faire abstraction de question de différenciation des produits. Lorsque les consommateurs valorisent à la fois la qualité environnementale mais aussi la diversité des produits vendus sur le marché, on étudie dans le chapitre 3 les moyens de provision d'un niveau de qualité socialement désirable.

Le choix de la qualité environnementale est une décision stratégique pour l'entreprise.

La littérature établit que, du point de vue d'un régulateur bienveillant, un agent privé choisit un niveau de qualité environnementale sous-optimal (la qualité ayant les attributs d'un bien public). Le chapitre 3 comprend un modèle stylisé d'un duopole caractérisé par des producteurs de la qualité verte (relativement propre) et brune (conventionnelle) verticalement différenciés. Le pouvoir de marché est partagé entre les deux firmes qui se concurrencent en quantité. Ce pouvoir augmente avec la hausse de la qualité environnementale permettant une différenciation plus prononcée.

On part d'un modèle de référence dans lequel le niveau de qualité environnementale choisi est sous-optimal. Dans ces conditions, on s'interroge sur la durabilité et la stabilité de cette stratégie. L'équilibre est caractérisé par un profit plus faible pour la firme brune que pour la verte. N'ayant pas une possibilité d'une déviation profitable, le profit de la firme brune est pourtant strictement croissant en fonction de la qualité environnementale. La firme brune aurait intérêt à inciter sa concurrente à distordre son choix de qualité

environnementale vers le haut. L'entreprise verte, à son tour, en anticipant la gêne de la firme brune concernant le rapport des profits, vise à s'assurer la position dictatrice en termes du choix de qualité environnementale sur le marché. L'objectif est de dissuader l'entreprise brune de toute tentative de déviation.

On étudie donc le choix optimal de qualité environnementale dans un cadre d'une organisation des producteurs qui permet aux entreprises de communiquer afin de se coordonner. Ce choix de long terme qui favorise l'intérêt mutuel n'assure pourtant pas un niveau de qualité environnementale socialement désirable.

Afin de tenir compte du dommage environnemental, on intègre au modèle la pression sociétale d'une ONG sur les entreprises. Menaçant d'une publicité nocive, l'ONG peut inciter l'organisation des producteurs à internaliser leur empreinte environnementale dans la décision interne. On constate que cette mesure n'atteint pas non plus le niveau de qualité environnementale socialement optimal. En effet, l'organisation ne prend pas en compte la valeur attribuée à la diversité des biens sur le marché par les consommateurs.

Cette défaillance nous renvoie aux questions principales suivantes : quel est le mécanisme d'incitation qui serait à la fois puissant et efficace ? Quels sont les coûts associés à la tentative d'accorder un rôle social à une structure privée ? Enfin, le marché correctement ajusté peut-il véritablement corriger les externalités ?

General Introduction

While the general notion of quality has evolved over the centuries for certain products, such as French wines and cheeses, the concept of environmental quality is relatively recent. It arose together with mass production, with the ambition to ensure high financial gain while neglecting the impact of industrialization on the environment.

The standards of environmental quality are beginning to enter the technical specifications of a large range of products. Having become a central and strategic feature of a product, environmental quality concerns all the agents in a market. Consumers start to develop an authentic taste for environmental quality; firms are looking to meet their expectations, while the regulator is concerned with market deficiencies. The general tendency of globalization and deregulation has given non-government organizations (NGOs) a particular role to fill in the shortcoming of public interest. They undertake initiatives to influence public opinion, inform and educate consumers' choices, try to enforce businesses to internalize their actions. The growing public awareness of environmental issues leads ultimately to changes in public policies. The imposition of environmental regulation is the subject of Chapters 1 and 2.

We examine how tax avoidance affects the optimal design of a linear tax on polluting emissions in a monopoly setting. The firm is owned by shareholders who differ in their cost of tax dodging. Following Buchanan (1969), the optimal tax should correct two negative externalities due to pollution and the monopolist's behavior. The analysis highlights two conflicting effects of tax avoidance on the environmental policy design: a *free-riding effect* and a *tax base erosion effect*. With heterogeneous tax avoidance, the regulator must also internalize the externality imposed by the free-riding of tax avoiders on the rest of the society. This free-riding makes the regulator either impotent or unfair, depending on the severity of the environmental damage and the firm's efficiency. We also show that a two-part tax schedule can achieve the first-best outcome.

Apart from the behavioral response in the form of tax avoidance, the environmental

taxation can also evoke a strategic response at the firm's level. This is the subject of Chapter 2. Motivated by a price premium on high environmental quality, the clean (non-polluting) firm has an interest to credibly transmit information about its environmental performance in order to benefit from consumers' willingness to pay more for high quality. At the same time, the dirty (polluting) firm can free-ride on enthusiastic consumers' expectations about environmental quality and imitate the clean type. Chapter 2 is dedicated to the analysis of strategic actions of a firm that faces the problem of information asymmetry.

The article studies how incomplete information affects the optimal second-best environmental tax in a monopoly setting.

Our contribution is to endogenize the pollution tax and to analyze its impact on social welfare. We show that for either pooling or separating equilibrium, the optimal tax must be set below the level required for a polluting monopoly under complete information. The tax is composed of three elements to correct corresponding market distortions. The first is the Pigouvain standard that is to internalize the pollution externality. The second adjusts the tax because of monopolistic pricing which holds back output to extract the non-competitive rent. The third and novel element is to account for information asymmetry. As the tax enters the price of either variety under separating and pooling equilibria, consumers' expectations of high environmental quality determine the value of the clean product, the trade of which is inevitably restrained by the pollution tax. Hence, the regulator who places a corresponding value on the clean variety scales down the optimal tax level.

We distinguish two forms of regulation: (i) a weak regulation which preserves the cost advantage of the polluting monopoly; (ii) a strong regulation which grants the cost advantage to the clean monopoly.

While under pooling, the pollution tax equalizes the expected social value to the expected social cost of the product. This is no longer attainable under separating equilibrium. The clean monopolist sets the price at a suboptimal level in the presence of

information asymmetry. His reaction to price change induced by the tax depends on the relative position of the price in relation to the profit-maximizing level. With weak regulation, the expected product price exceeds its expected social cost and vice versa occurs with strong regulation.

A welfare analysis gives the following results: environmental regulation reduces the profit of the polluting monopoly, be it pooling or separating equilibrium. Environmental regulation augments the profit of the clean monopoly under strong regulation and under pooling equilibrium. Yet, surplus of consumers for the clean variety is generally reduced subsequent to regulation.

Finally, we study the optimal choice of environmental quality at a firm's level relative to what a welfare-maximizing regulator would desire. This choice cannot be considered in the abstract from the issue of product differentiation. When consumers value high environmental quality as well as the diversity of products sold in the market, the private quality choice is insufficient. We explore in Chapter 3 the means that are necessary to attain the socially optimal level of environmental quality.

In a stylized model of vertically differentiated brown-green duopoly, two firms with market power that increases in environmental quality are competing in product quantities.

In a baseline model, we derive the privately supplied level of environmental quality and show, in line with the literature, that this level is suboptimal compared to what a benevolent regulator would desire. We argue that this equilibrium might be unstable in the long run because the firms generate unequal profits which provides an incentive to coordinate their action: for the brown firm to benefit from a greater quality differentiation, and for the green firm to ensure the leadership position in the choice of environmental quality.

We thus adjust the model to allow for producers' coordination, as well as with increased environmental awareness induced by the threat of NGO's negative publicity. For every case under consideration, the privately chosen environmental quality falls short of the socially desirable level. Hence, in context of a global tendency of deregulation of markets, entrusting implementation of public interests to a private entity may call for caution.

Part I

Tax Avoidance

Chapter 1

Free-riding on environmental taxation

We examine how tax avoidance affects the optimal design of a linear tax on polluting emissions in a monopoly setting. The firm is owned by shareholder who differ in their cost of tax dodging. Following Buchanan (1969), the optimal tax should correct for two negative externalities due to pollution and the monopolist's behavior. The analysis highlights two conflicting effects of tax avoidance on the environmental policy design: a *free-riding effect* and a *tax base erosion effect*. With heterogeneous tax avoidance, the regulator must also internalize the externality imposed by the free-riding of tax avoiders on the rest of the society. This free-riding makes the regulator either impotent or unfair, depending on the severity of the environmental damage and the firm's efficiency. We also show that a two-part tax schedule can achieve the first-best outcome.

Keywords: Environmental Taxation, Monopoly, Tax Avoidance.

JEL Code: D43, D82, H23, L12, Q28

Résumé du Chapitre 1

Le chapitre 1 étudie l'impact de l'évitement fiscal sur la taxation optimale de second rang portant sur les émissions polluantes d'un monopole. L'entreprise est détenue par des actionnaires hétérogènes dans leur capacité d'esquiver le fisc. La conformité de l'entreprise à la taxation environnementale est déterminée en fonction des coûts d'évitement. Elle dépend du niveau de la taxe. Lorsque la taxe augmente, la non-conformité devient attractive pour un plus grand nombre d'actionnaires. Dans la tradition de Buchanan (1969), la taxe optimale devrait corriger les deux externalités négatives qui proviennent de la pollution et du comportement en situation de monopole. La capacité à échapper le fisc introduit un nouveau paramètre de décision. L'analyse fait apparaître de deux effets opposés de l'évitement fiscal sur le design de la politique environnementale : l'effet d'un comportement de passager clandestin des actionnaires et l'effet de l'érosion de l'assiette fiscale suite à une hausse de taxe. Le mécanisme que la taxe déclenche est le suivant : lorsque la non-conformité augmente, le niveau de la taxe doit aussi augmenter, ce qui entraîne, par conséquent, encore plus d'esquive. Etant donnée l'hétérogénéité des actionnaires face à l'évitement fiscal, le régulateur doit internaliser l'externalité imposée par le comportement de passager clandestin de l'entreprise sur le reste de la société. La taxe optimale doit équilibrer ces deux effets opposés. Le comportement de passager clandestin rend le régulateur soit impuissant, soit inéquitable en fonction de la sévérité du dommage environnemental et de l'efficacité de l'entreprise. Dans le cadre d'un dommage modéré où la taxation à la Buchanan aurait été instaurée, le régulateur s'abstient de la régulation car la perte des contribuables serait plus coûteuse pour la société que le gain de correction de l'externalité environnementale. Pour un dommage considérable, la taxe doit dépasser le niveau de Buchanan. En conclusion, quand la politique environnementale est mise en place, les consommateurs en supportent le fardeau financier. Dans le cas contraire, ils supportent la pollution. Nous démontrons par ailleurs qu'un programme d'une taxe à deux parties peut atteindre la solution du premier rang.

1.1 Introduction

Economists have long advocated for high Pigouvian taxes that would directly place prices on the most harmful of greenhouse gases to achieve significant reductions of those. For instance, the optimal Pigouvian tax on carbon dioxide should be set in the range of \$75 to \$175 per ton according to the best estimates of marginal damages of emissions (Stavins 2011). Although environmental taxation has great conceptual appeal, economists also recognize the challenge of inducing tax payers to comply with taxes at such high rates. Surprisingly enough, the concern formerly expressed by Adam Smith is rarely invoked in this respect:

“High taxes, sometimes by diminishing the consumption of the taxed commodities, and sometimes by encouraging smuggling, frequently afford a smaller revenue to government than what might be drawn from more moderate taxes” (Smith 1776, Book V, Chapter II).

Long after publication of *The Wealth of Nations*, Arthur Laffer drew his famous curve illustrating the possibility of an inverse relationship between tax rates and government revenue (Laffer 1977). Understood in a broad metaphoric sense, the term “smuggling” used by Adam Smith may refer to a variety of tax dodging in today’s economies, ranging from the relocation of a corporation’s legal domicile to a lower-tax nation, usually known as tax inversion, to the substitution between labor and leisure discussed in general equilibrium models (see (Fullerton 1982), for instance). The type of “smuggling” we examine here is *tax avoidance*, referring to all the transactions that take advantage of legal loopholes to reduce total tax liabilities¹.

Fiscal avoidance exerts a negative influence on the ability of governments to implement an optimal environmental regulation. This has been recognized in the incentive regulation

¹More precisely, throughout the article, we will use the term “tax avoidance” in the sense of “abusive tax avoidance transactions” (GAO 2011), that is, all the practices that don’t contradict the law but diverge from its spirit. For instance, a company that uses artificial non-productive transactions through offshore entities with complex but legal profit-shifting techniques is involved in abusive avoidance, as it uses loopholes in law to optimize tax obligations in the ways not intended by the legislation.

(Slemrod 2007) distinguishes tax avoidance from illegal tax evasion, although he highlights the difficulty of distinguishing illegal from legal intent on the part of a taxpayer.

literature for the case where the regulator cannot observe the costs of polluters' abatement alternatives. 'Foreign' shareholders of a polluting firm — those who reside outside the regulator's jurisdiction — are identified as prone to escape taxation (Baron 1985, p. 218). Real-world examples are multinational corporations operating upstream in the supply chain of carbon-intensive goods, such as French Total, LafargeHolcim (the cement giant of merged french Lafarge and Swiss Holcim), German BASF or Russian GazProm. The presence of foreign capital in the shareholders structure of these polluting firms varies from 30 to 70%. Hence, a regulator puts unequal weights on corporate profits as on consumers' surplus. As profits are partly excluded from the social welfare function, the regulator fails to fully refund the tax revenues to consumers — all of whom reside in the regulator's jurisdiction — which ultimately entails a welfare loss.

Similarly, (Spulber 1988), (Laffont 1994), or (Lewis 1996) acknowledge that the cost of transferring the emission tax from the polluter to the polluted limits the governance capacity of an environmental regulator. The social cost of raising public funds in these models raises a distributional problem, which amounts again to favoring consumers' over producer's interests in the regulator's objective function. The cost of public funds is traditionally justified by the use of distortionary taxation for raising funds, but it might be attributable to fiscal avoidance. A general insight is that, given an exogenous reduction of the tax base, the regulator must amend the environmental tax design accordingly². Surprisingly enough, this literature has not considered the possibility that the environmental regulator adopts the means to influence the decision to avoid taxation. If the purpose of environmental taxation is to force individuals to consider the full set of consequences from polluting emissions, the tax should also internalize the externality caused

²In (Baron 1985), the foregone tax revenue combined with the information problem leads the environmental regulator to use an emission tax as a penalty aimed at diminishing the incentive to misreport information. In (Laffont 1994) and (Lewis 1996), fiscal avoidance imposes on the environmental regulator through changes in the social cost of public funds. It turns out that fiscal avoidance under asymmetric information modifies the Pigouvian taxation because the need of an incentive correction hinges on the fiscal transfer between the polluting firm and consumers. The higher the cost of raising funds, the higher the information rent captured by the truth-telling firm, the greater the deviation from the Pigouvian taxation.

by the trouble transferring tax.

In this paper we assume that the environmental regulator is able to deal with tax avoidance, thereby controlling tax payment by the firm's shareholders instead of undergoing it. There is evidence of a substantial heterogeneity in tax avoidance (Christian 1994). Among the shareholders of a polluting firm, there are some who comply with taxation, and some who do not. The model in (Baron 1985) suggests that tax avoidance arises from differences in the shareholders' residential location, which involves various cost-benefit calculations. In (Slemrod and Yitzhaki 2002), tax avoidance mostly involves high-income individuals and depends on regulatory expenditures on enforcement. The heterogeneity in tax avoidance can also be explained by differences in intrinsic motivation such as civic virtue, as argued by (Frey 1997). In our setting, firm's shareholders differ in their opportunity to avoid taxation. Our model departs from (Slemrod 1994) in that the regulator controls the extent of tax avoidance through the design of the environmental tax rather than through an enforcement mechanism.

When the polluting firm has no information rent, (Laffont 1994) shows that the Pigouvian tax leads to internalize correctly the environmental externality and a lump-sum tax on profit solves the distributional problem. This result suggests that, if the regulator could observe the cost of abating pollution, tax avoidance would not be an issue provided that the combination of two instruments, namely the tax per unit of emissions and the lump-sum taxation on profit, is available. We adopt a different perspective and consider that the regulator is armed only with a tax on polluting emissions. Unlike (Laffont 1994), the regulator in our model is able to modify the amount of transfers that must be handed back to consumers. Fiscal avoidance undermines the regulator's commitment to redistribute the tax yields, leading to an endogenous disturbance in tax transfer. Building on (Baron 1985), we assume that the regulator's objective excludes part of the monopoly profits belonging to the shareholders who avoid taxation. However, unlike Baron, the regulator influences the changes in the tax base by setting the second-best optimal tax rate. Our analysis differs further in that it abstracts from information

asymmetry and assumes environmentally conscious consumers, implying that consumer disutility of pollution internalizes, to some extent, the environmental damage.

We shed light on adverse effects from the free-riding of tax avoiders on the efficiency of environmental regulation. In a partial equilibrium setting where a regulator levies an environmental tax to correct for the polluting behavior of a monopolistic firm, we characterize optimal taxation, assuming that firms' shareholders can choose between paying and avoiding the tax. That is, we consider the second-best problem of choosing the welfare-maximizing tax for which the regulator endogenizes the free-riding behaviors of tax avoiders.

In a recent work based on the “World Induced Technical Change Hybrid” model, (Carraro, Favero, and Massetti 2012) predict that carbon taxes might sometimes generate fiscal revenues which first increase, then achieve the highest levels of revenue, and finally decrease, thereby forming a “carbon Laffer” curve (p. 25). Their analysis questions the political and economic feasibility of large taxation schemes. We raise similar concerns regarding a polluting monopolist, following the tradition of (Buchanan 1969). As has been thoroughly formalized by (Lee 1975) and (Barnett 1980), the regulator must scale down the environmental tax below the Pigouvian level to correct for the monopolist's tendency to underproduce. Therefore, compared to markets with perfect competition, the emissions control of imperfectly competitive firms requires a less stringent taxation. We take a fresh look at this second-best policy and examine how the environmental regulator copes with the possibility that the firm's shareholders bypass taxation. Clearly, this is an issue of theoretical importance. If the purpose of environmental taxation is to force individuals to consider the full set of consequences from polluting emissions, the optimal tax should also internalize the negative externality caused by the free-riding of tax avoiders.

Furthermore, tax avoidance has emerged as a systemic problem with the globalization of the economy. The deregulation of the financial system in industrialized countries, which took place in the 1980s, together with the technological progress, has made the

mobility of capital far greater than that of labor. While labor mobility is largely limited to national jurisdiction, the capital can almost instantaneously move around the globe. As a result, almost every multinational firm is to some extent involved in avoidance activities (Christensen and Kapoor 2004, p. 9). Indeed, many multinational companies such as Apple, Amazon and Microsoft (Young 2013) or Starbucks, Total and Colgate (Harel 2012) have drawn public attention for remarkably low taxes paid on profit. More importantly for our purposes, tax avoidance is closely related to companies operating in greenhouse gas producing sectors, including the extractive industries, aviation, shipping, pharmaceuticals, traded commodities and weapons industry (Christensen and Kapoor 2004, p. 3).

As pointed out by the optimal taxation literature, avoidance or sheltering is the behavioral response to taxation where an individual searches a legal opportunity to reduce his tax liability (Cowell 1990). Besides this issue, the mainstream literature on avoidance is concerned with optimal enforcement expenditure (Mayshar 1991) and (Slemrod 1994). In the present paper, we ignore income effects and abstract from enforcement efforts to focus on the impact of tax avoidance on environmental regulation; only the effect of diminishing the tax base caused by tax sheltering is under consideration. To our knowledge, the concern of tax base erosion has not yet been addressed in the field of environmental economic. The only study of environmental tax evasion belongs to (Liu 2013) who questions its impact on environmental taxation. He shows in a generalized equilibrium model with perfect competition that an environmental tax may enhance welfare provided that environmental tax is more difficult to evade than other ‘regular’ taxes.

In our framework, the firm’s profit is distributed to shareholders who differ in their opportunity cost of avoiding taxation. They will gradually bypass taxation as the tax rate increases. Hence, the regulator’s objective function excludes part of the monopoly profits attributable to tax avoidance. The environmental tax is designed so that the regulator optimally chooses the level of tax avoidance compatible with the dual task of

internalizing the polluting externality and mitigating the monopolist's overpricing. The analysis highlights two conflicting effects of tax avoidance on the environmental policy design: a *free-riding effect* and a *tax base erosion effect*. On the one hand, tax avoiders free-ride on tax payers as well as consumers by passing on to them the burden of the tax. The regulator internalizes this externality by taxing the complying shareholders more heavily than it would do under full compliance. On the other hand, the regulator must take into consideration that the tax increase will induce more shareholders to avoid taxation. As shrinking tax base reduces tax revenues, the regulator has an opposite incentive to soften taxation in order to compensate for the shareholders' mobility. As a result, depending on which effect of tax avoidance prevails, the second-best optimal taxation proves more or less severe relative to full compliance.

We find that the tax base erosion effect dominates when the monopolist is rather clean and the polluting good is relatively inexpensive to produce, so that environment has a low rank in the agenda of economic priorities. The regulator gives up a positive tax that would otherwise internalize the monopolist's environmental externality under full tax compliance, for the sake of maintaining the tax base. Anticipating that positive taxation would induce some shareholders with low costs of avoidance to escape, the regulator refrains from taxation. This may somewhat explain the sluggishness in introducing carbon taxes when the focus on economic growth takes priority over the environmental concern. If, on the contrary, the monopolist is rather dirty and/or moderately efficient, the environmental damage becomes the major concern and the free-riding effect of tax avoidance dominates. To cope with the dire need of internalizing the polluting externality, the regulator can no longer afford not to tax emissions. Instead, the regulator taxes pollution at the cost of losing shareholders. The revenue lost as a result of tax avoidance creates a further negative externality on those who bear the burden of environmental taxation. These are the shareholders who remain under the regulator's authority, as well as the consumers who pay the monopoly price inflated by the tax. To correct for the tax avoiders' free-riding, the regulator must raise the environmental tax above the level

recommended by (Buchanan 1969). Consequently, the remaining taxpayers must bear a greater tax than that under no tax avoidance.

We finally allow the regulator to use the combination of a unit tax on emissions and a lump-sum tax. We show that this two-part tax schedule successfully achieves the first-best outcome in our setting.

The present article is organized as follows. In Section 1.2, we set up the formal model. Section 1.3 characterizes the second-best optimal tax under the assumption of tax avoidance. Section 1.4 examines the use of the two-part tax schedule. In Section 1.5, we present a brief history intended to illustrate the reluctance of an environmental regulator to correct for the environmental externality because of tax avoidance. Section 1.7 concludes.

1.2 The model

The industry consists of a single polluting firm, the firm's shareholders, consumers and an environmental regulator.

The firm produces quantity q of a good that releases the amount $(1 - e)q$ of polluting emissions, where parameter $e \in [0, 1]$ represents the state of the abatement technology. If, for instance, polluting emissions are greenhouse gases and the good is electricity, e measures the use of non-emitting methods such as hydroelectric, nuclear, or geothermal, and $1 - e$ the use of emitting methods through the combustion of coal, natural gas, or petroleum distillates. We restrict attention to short-run decisions, so that the level e is not a decision variable. If the abatement is at a maximum, the emissions are zero. If no abatement is undertaken, the emissions are equal to the output. The overall marginal cost of producing the good is $c(e)$, with $c'(e) > 0$, meaning that devoting more resources to abatement raises the overall cost of production. Industry-specific emissions cause environmental damage $d(q, e)$, which is assumed to be strictly proportional to the amount of polluting emissions: $d(q, e) = \delta(1 - e)q$, where $\delta > 0$ measures the marginal damage

from emissions.

The regulator is facing two market distortions due, respectively, to monopoly power and environmental externality. In that event, we know from (Buchanan 1969) and (Barnett 1980) that a second-best optimal policy strikes the balance between the need to correct for the monopolistic behavior and the Pigouvian task of internalizing the marginal social damage. To allow comparison with this literature, we assume that the regulator is benevolent and the only regulatory instrument available to correct for both distortions is a tax τ per unit of emissions. Hence, throughout the article, the environmental tax can be thought of as the application of a broader regulatory policy: besides being concerned with the environment, the regulator is also responsible for controlling the market price. In other terms, the regulator is wearing two hats, that of an environmental protection agency and a public utility commission. A tax will take negative values if it turns out to be a subsidy. Indeed, it is conceivable that the tax cut resulting from the need to correct for the firms' market power becomes so sharp that the optimal policy imposes to subsidize the product.

The firm is owned by a continuum of shareholders, holding one unit of profit each. We normalize the mass of shareholders to be one. For simplicity, we will assume, first, that a shareholder has valuation 1 for holding one unit of profit, and second, that a shareholder incurs a cost $\alpha \in [0, 1]$ of fiscal optimization. Hence, a shareholder with a cost α gets the surplus $1 - \alpha$ from tax dodging. Paying the cost α may help the shareholder economize on the amount $\tau(1 - e)$ of the due tax. For instance, α is the cost of sourcing out for the best way of being tax exempt. In practice, there exists a market for tax optimization services. Banks offer their corporate and private clients services such as wealth management, which contain "recommendations" for organizing their fiscal obligations in the most beneficial way (Gravelle 2013). Alternatively, an internal department of the firm may specialize in tax issues, screening for countries where a subsidiary would benefit from the most favorable tax regimes. From (Christian 1994), there is evidence of a substantial heterogeneity in tax avoidance. This will be captured

by assuming that shareholders differ according to α , which is uniformly distributed on $[0, 1]$. Now consider the behavior of a shareholder whose objective is to maximize surplus. The shareholder $\hat{\alpha}(\tau)$ who is indifferent between paying and avoiding the environmental tax is determined by

$$1 - \tau(1 - e) = 1 - \hat{\alpha}(\tau), \quad (1.1)$$

which implies that the fraction of shareholders who comply with taxation is given by $1 - \hat{\alpha}(\tau)$, provided that $0 < \tau < \frac{1}{1-e}$. If $\tau \leq 0$, the environmental policy takes the form of a subsidy, and there is full compliance. Moreover, if $\tau \geq \frac{1}{1-e}$, then all the shareholders bypass taxation. Let $\beta(\tau)$ denote the compliance rate for taxation:

$$\beta(\tau) = \begin{cases} 1 & \text{if } \tau \leq 0, \\ 1 - \tau(1 - e) & \text{if } 0 \leq \tau \leq \frac{1}{1-e}, \\ 0 & \text{if } \frac{1}{1-e} \leq \tau \leq \frac{v-c(e)}{1-e}. \end{cases} \quad (1.2)$$

The monopolist sells the polluting good to a continuum of risk-neutral consumers with heterogenous “green” preferences. Each consumer purchases at most one unit of the good, which thus indirectly generates the amount $1 - e$ of polluting emissions via consumption. Although consumers have a common reservation price v , they differ in their tastes for the good due to their personal dislike of pollution. For a given consumer X , the dislike of pollution is measured by the monetary loss $(1 - e)X$, which, besides psychic discomfort, may represent health care expenditure and all the adaptation costs to the polluted environment. The heterogeneity of preferences may also reflect various degrees of social environmental conscience among consumers. If, for instance, the good is fossil energy, consumers may differ in their aversion to the negative impact on global warming, and if it is nuclear energy, they may differ in their dislike of the potential risks imposed on future generations by nuclear repositories. To simplify the analysis, we make the assumption that X is uniformly distributed along a segment of unit length, which is convenient to generate a linear demand function. Hence, consumers distinct

from 0 partly internalize the polluting externality, and none of them fully internalizes it as long as $1 < \delta$. The total number of consumers is normalized to unity. Assuming that consumers receive zero surplus from consuming outside goods, consumer X derives a surplus $v - (1 - e)X - p$ from purchasing the good at price p , which yields the demand function

$$D(p, e) = \begin{cases} 0 & \text{if } p \geq v, \\ \frac{v-p}{1-e} & \text{if } v - (1 - e) \leq p \leq v, \\ 1 & \text{if } p \leq v - (1 - e). \end{cases} \quad (1.3)$$

Socially optimal allocation of the good.—The welfare function is the conventional one of gross benefits to consumers less production and pollution costs. The welfare function is

$$\begin{aligned} W(X) &= \int_0^X [v - c(e) - (1 - e)x - \delta(1 - e)] dx \\ &= [v - c(e) - \delta(1 - e)]X - (1 - e)\frac{X^2}{2}. \end{aligned} \quad (1.4)$$

The expression $\delta(1 - e)X$ is the actual damage caused to the environment, while $(1 - e)\frac{X^2}{2}$ represents the monetary equivalent of the consumer's dislike for pollution³.

At the socially optimal solution, the marginal consumer X^* solves equation $v - (1 - e)X^* = c(e) + \delta(1 - e)$ so that the marginal social value of the good $v - (1 - e)X^*$ must exactly offset the total social marginal cost $c(e) + \delta(1 - e)$. Thus from the social standpoint, the market size should be

$$X^* = \frac{v - c(e)}{1 - e} - \delta. \quad (1.5)$$

To ensure that the good is socially desirable, we will restrict the parameters of the

³The model in (Kurtyka and Mahenc 2011) with heterogeneous preferences for the environment results in the same distinction between the actual damage to the environment and consumer adaptation costs.

model to satisfy the following assumption:

$$(1 - e) \delta \leq v - c(e). \quad (1.6)$$

We will abbreviate the marginal social cost of pollution $(1 - e) \delta$ by MSC, and $v - c(e)$, the marginal social value of the good, net of its production cost, absent any environmental consideration, by MSV.

Monopolist's behavior in the absence of regulation. — The monopoly profit is $\pi_e(p, e) = (p - c(e))D(p, e)$ and the first-order condition for the monopolist's optimization problem is given by

$$(p - c(e)) \frac{\partial D(p, e)}{\partial p} + D(p, e) = 0. \quad (1.7)$$

One can easily check that the second-order conditions are satisfied. Let $\varepsilon(p) = -\frac{\partial D(p, e)}{\partial p} \frac{p}{D(p, e)} = \frac{1}{1-e} \frac{p}{D(p, e)}$ denote the price elasticity of demand for the good. We further denote by \hat{p}_e the price set by the unregulated monopolist. The first-order conditions can be rewritten in the usual way to show that the Lerner index is equal to the inverse of the price elasticity of demand, which implies that market power is a decreasing function of the price elasticity of demand:

$$\frac{\hat{p}_e - c(e)}{\hat{p}_e} = \frac{1}{\varepsilon(\hat{p}_e)}, \quad (1.8)$$

where $\varepsilon(\hat{p}_e) = \frac{\hat{p}_e}{v - \hat{p}_e}$. Substituting this expression into the right-hand side of (1.8), we obtain the monopoly price $\hat{p}_e = \frac{v+c(e)}{2}$, and the resulting demand is $D(\hat{p}_e, e) = \frac{v-c(e)}{2(1-e)}$. Comparing this outcome to the socially optimal solution, two separate cases emerge within the parameter configuration defined by (1.6). In one case where $(1 - e) \delta \leq \frac{v-c(e)}{2}$, the MSC is low relative to the MSV— say, because the monopolist is significantly clean and efficient —, and we have $D(\hat{p}_e, e) \leq X^*$: the monopolist's production is lower than that implied by the socially optimal solution. Following the policy recommendations from (Buchanan 1969) or (Barnett 1980), the regulator should rely on the monopolist's

tendency to underproduce and scale down the environmental tax below the Pigouvian level (possibly until the tax turns into a subsidy paid to the firm for fairly low values of the MSC). In the other case where the MSC $(1 - e) \delta$ exceeds $\frac{v-c(e)}{2}$ — the monopolist is significantly dirty or moderately efficient —, we have $D(\hat{p}_e, e) > X^*$, so that the monopolist by itself produces too much of the polluting good. In that case, the monopolist is no longer ‘the environmentalist’s best friend’; the second-best optimal policy calls for a regulation more stringent than in the previous case.

Lemma 1 summarizes this discussion.

Lemma 1 *Under Assumption (1.6), in the absence of regulation, the monopolist underproduces relative to what would be socially desirable when $(1 - e) \delta < \frac{v-c(e)}{2}$, and otherwise, the monopolist overproduces.*

1.3 Second-best optimal tax

We now consider the second-best problem faced by a welfare-maximizing regulator who can control the pollution emitted by the firm but not its monopolistic behavior. Hence, the regulator cannot ensure that the firm will behave as a price-taker. We further assume that the regulator is a Stackelberg leader who commits to a policy. Thus, we model the policy implementation as a two-stage game. In the first stage, the regulator specifies a tax τ on each unit of emissions that maximizes the social welfare $W(\tau)$ and generates the revenue $R(\tau)$. We allow τ to be negative, in which case it will be a subsidy paid to the firm instead of a tax. The regulator is also committed to transferring all tax yields to consumers. Stage two is the production period. In this stage, the monopolist sets the price of the good, the consumers decide whether to purchase the good, and the shareholders decide whether to comply with taxation. Should a shareholder decide to avoid taxation, it must incur its own cost of fiscal optimization. This sequence of play amounts to assuming that the regulatory policy has a commitment value, so that, once made, the choice of τ cannot be reversed in stage two, and the regulator cannot renege

on his commitment to transfer the tax yields to consumers.

Denoting by $p_e(\tau)$ the monopoly price under regulation, the tax base is $(1 - e)D(p_e(\tau), e) = v - p_e(\tau)$, and the expected emissions payments $R(\tau)$ correspond to the fiscal revenue corrected by the compliance rate

$$R(\tau) = \beta(\tau) \tau(v - p_e(\tau)). \quad (1.9)$$

As will be seen later, $R(\tau)$ plots the fiscal revenue as a function of the environmental tax, yielding a new variant of the Laffer curve. Furthermore, tax avoidance drives a wedge between $R(\tau)$ and the total amount of tax yields to be transferred to consumers, that is, $\tau(1 - e)D(p_e(\tau), e) = \tau(v - p_e(\tau))$.

Anticipating tax avoidance, the regulator recognizes that part of the corporate profit escapes the regulator's jurisdiction, which distorts the refund of the tax proceeds to consumers. Hence, the regulator only takes into consideration the complying part of producer surplus in the welfare function. The regulator's problem is to choose the tax that maximizes the social welfare function

$$W(\tau) = \int_0^{D(p_e(\tau), e)} [v - (1 - e)x - \delta(1 - e) - p_e(\tau) + \tau(1 - e)] dx + \beta(\tau) \pi_e(p_e(\tau), e), \quad (1.10)$$

taking as given the firm's noncompetitive behavior. As will be shown, the regulator mobilizes the force of the monopoly power to generate a socially beneficial allocation of the good.

We concentrate first on the firm's monopolistic behavior. The profit is $\pi_e(p_e(\tau)) = (p_e(\tau) - c(e) - \tau(1 - e))D(p_e(\tau), e)$, and the first-order condition for profit maximization can be rearranged to compute the Lerner index of the regulated monopolist

$$\frac{p_e(\tau) - c(e)}{p_e(\tau)} = \frac{\tau(1 - e)}{p_e(\tau)} + \frac{1}{\varepsilon(p_e(\tau))}, \quad (1.11)$$

or, equivalently,

$$p_e(\tau) = \frac{v + c(e) + \tau(1 - e)}{2}. \quad (1.12)$$

The regulator will take this monopoly price into consideration to implement the environmental policy. Clearly, we can see from (1.11) that, besides internalizing the environmental externality, the regulator will employ the environmental tax to correct for the externality exerted on the society by the monopolistic behavior. Moreover, the comparison between the monopoly prices \hat{p}_e given by (1.8) and $p_e(\tau)$ given above shows that the environmental tax will be partly passed on to consumers in a higher price for their polluting good purchases.

Substituting (1.12) and (1.2) into (1.9) leads to the following relationship between tax rates and fiscal revenue:

$$R(\tau) = \begin{cases} \frac{\tau}{2} (1 - \tau(1 - e)) (v - c(e) - \tau(1 - e)) & \text{if } 0 \leq \tau \leq \frac{1}{(1-e)}, \\ 0 & \text{if } \frac{1}{(1-e)} \leq \tau \leq \frac{v-c(e)}{1-e}. \end{cases} \quad (1.13)$$

Some calculations given in Appendix 1.8.1 show that $R(\tau)$ reaches a maximum at $\hat{\tau}$, falls to zero at $\tau = \frac{1}{(1-e)}$, and remains zero on the interval $\left[\frac{1}{1-e}, \frac{v-c(e)}{1-e}\right]$, where tax rates are so high that all the shareholders bypass taxation (see (1.2)). Figure 1 represents $R(\tau)$ with respect to τ as a solid line. This curve is always lower than the dotted curve $R_n(\tau)$ that depicts the fiscal revenue in the absence of tax avoidance, that is, when $\beta(\tau) = 1$ for all τ (the expression of $R_n(\tau)$ is relegated to Appendix 1.8.1). Interestingly enough, fiscal revenues in both regimes of avoidance and compliance are consistent with the statement by (Dupuit 1844):

“By thus gradually increasing the tax it will reach a level at which the yield is at a maximum . . . Beyond, the yield of tax diminishes . . . Lastly a tax will yield nothing”.

This early insight into the existence of a revenue maximizing tax was later illustrated by the Laffer curve.

Like the Laffer curve, the two curves in Figure 1-1 exhibit a downward-sloping segment for high tax rates, known as the “prohibitive” range because the same revenues can

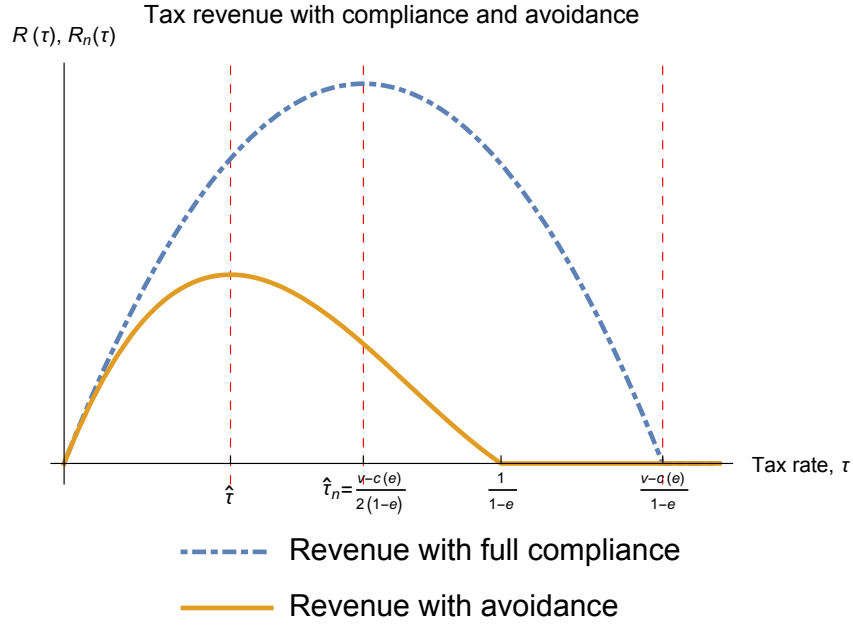


Figure 1-1: Laffer Curve

be collected at lower tax rates (Fullerton 1982). General equilibrium models such as that used by (Fullerton 1982) in a perfectly competitive regime, have highlighted the importance of income effects and substitution effects between labor and leisure in explaining the emergence of a negative relationship between tax rates and fiscal revenue. The reasons for this are clearly different in the present setting since our partial equilibrium approach focuses exclusively on the market for the polluting good while ignoring income effects. In the absence of tax avoidance, tax rates above $\hat{\tau}_n$ lower the revenue $R_n(\tau)$ because they raise the monopoly price and, finally, shrink the sales volume, thereby reducing the tax base down toward zero at $\tau = \frac{v-c(e)}{1-e}$. When shareholders have the possibility to avoid taxation, tax rates above the maximum $\hat{\tau}$ depress the revenue $R(\tau)$ even further because a growing number of shareholders with sufficiently low costs of fiscal optimization prefer to bypass rather than pay the tax, as its burden increases. Therefore, $R(\tau)$ falls gradually to zero, from $\hat{\tau}$ to $\tau = \frac{1}{(1-e)}$, where all the shareholders find it less costly to bypass taxation. If the regulator raises the tax above this threshold, but below $\tau \leq \frac{v-c(e)}{1-e}$, so that at least one consumer purchases the good, environmental taxes have no benefit and

the burden of environmental taxation is fully passed on to consumers through the price set by the monopolist. Finally, the comparison between $R_n(\tau)$ and $R(\tau)$ shows that tax avoidance extends the prohibitive range of the “environmental Laffer curve”.

Let us now examine how consideration of tax avoidance shapes the social welfare function. For this, we plug (1.12) and (1.2) into (1.10). After some calculations given in Appendix 1.8.2, we obtain that $W(\tau)$ is made of three parts due to the shareholders’ responses to taxation. When τ takes the form of a subsidy, no shareholder avoids taxation and $W(\tau)$ coincides with the function $W_n(\tau)$ on this range. For non-negative tax rates inside the interval $[0, \frac{1}{1-e}]$, the welfare $W(\tau)$ has a different functional form given by $W_p(\tau)$, due to the emergence of partial tax avoidance: some shareholders with sufficiently low costs of fiscal optimization prefer to bypass rather than pay the tax, and the foregone revenue entails a loss in social welfare. Finally, the welfare $W(\tau)$ turns into the function $W_f(\tau)$ for higher tax rates inside the interval $[\frac{1}{1-e}, \frac{v-c(e)}{1-e}]$, where there is full avoidance: in this range, the regulator has zero revenue from the tax since all the shareholders prefer to bypass it, and the burden of environmental taxation is fully passed on to consumers through the monopoly price.

Lemma 2 *The social welfare function can be decomposed into the following functions:*

$$W(\tau) = \begin{cases} W_n(\tau) & \text{if } \tau \leq 0 \text{ (no tax avoidance),} \\ W_p(\tau) & \text{if } 0 < \tau \leq \frac{1}{1-e} \text{ (partial tax avoidance),} \\ W_f(\tau) & \text{if } \frac{1}{1-e} < \tau \leq \frac{v-c(e)}{1-e} \text{ (full tax avoidance).} \end{cases} \quad (1.14)$$

Figure 1-2 displays the various forms that $W(\tau)$ can take, depending on the relative values of the MSV of the good and the MSC of pollution. As can be seen, the welfare functions exhibit two local maxima.

When the shape of the welfare function is that depicted in the upper left of Figure 1-2, the global maximum is a subsidy. Intuitively, this situation occurs when the MSC of pollution is low relative to the MSV of the good, meaning that the monopolist is significantly clean and the good is cheap to produce. If $(1 - e) \delta$ falls short of $\frac{v-c(e)}{2}$, Lemma 1

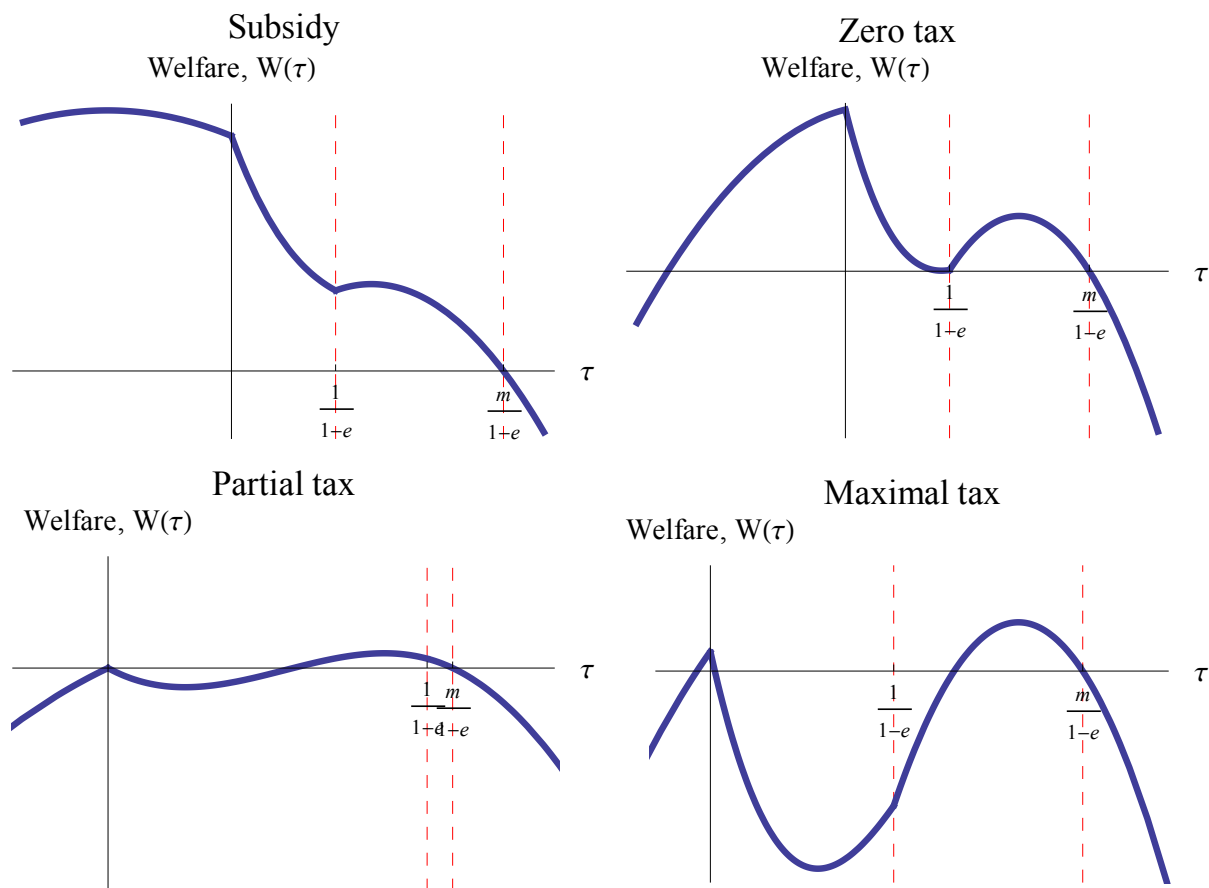


Figure 1-2: The forms of the Welfare function

tells us that the unregulated monopolist has a tendency to underproduce relative to what would be socially desirable. Hence, a positive tax would have the undesirable effect of inflating the price of the good, leading to the aforementioned effects on consumption and monopoly power, both detrimental to welfare. Rather, a subsidy has a desirable effect on price. The dual benefit of boosting consumption on the demand side and mitigating the upward pressure that the monopolists puts on price on the supply side, balances the adverse effect of increasing pollution. In addition, with a subsidy, the regulator does not need to worry about tax avoidance.

Regarding the three other welfare functions displayed in Figure 1-2, we suspect that the MSC of pollution is now high enough so that $(1 - e) \delta \geq \frac{v-c(e)}{2}$ holds, namely the monopolist is moderately clean or moderately efficient. For this parameter configuration,

we know from Lemma 1 that the monopolist produces too much of the polluting good from the social standpoint, unless the MSC of pollution coincides with the MSV of the good. The regulator should now consider taxing the monopolist rather than subsidizing the polluting output. If, by chance, there is a coincidence between $(1 - e) \delta$ and $\frac{v-c(e)}{2}$, Lemma 1 suggests that regulation is pointless since the monopolist is behaving in a socially efficient way on its own. It happens, however, that the three welfare functions other than that in the upper left of the figure depict situations in which there is a local maximum at zero tax, although the MSC of pollution exceeds the MSV of the good.

What is intriguing in the upper right of Figure 1-2 is that the local maximum at zero tax clearly dominates the local maximum resulting from positive taxation. This suggests that tax avoidance disrupts the previous balance between the environmental benefit of taxation and the detrimental upward pressure it puts on the monopoly price. We can guess that the fear of a novel adverse impact on welfare refrains the regulator from taxing the monopolist. From Proposition 3, we know that a positive tax, however light it is, induces the shareholders with the lowest costs of avoidance to bypass taxation. This immediately creates a welfare loss that can be seen at $\tau = 0$, where the slope of every welfare function turns from positive to negative. To offset this loss, the regulator must resort to a sharp increase in taxation, leading to the local maximum on the right-hand side of the welfare functions. The tax increase pays the bill for the free-riding of the tax avoiders, thereby enhancing welfare. However, this beneficial effect may not be sufficient to reach a welfare level higher than that obtained with the zero tax, as illustrated by the welfare function in the upper right of Figure 1-2. It is sufficient in the two remaining cases (the lower left and right of the figure), which suggests that the MSC of pollution is much greater than the MSV of the good, relative to the other cases. Although the positive tax fosters tax avoidance, it internalizes the externalities due to the tax avoiders' free-riding and the pollution as well.

Observe finally that, in the lower right of Figure 1-2, the monopolist is significantly dirty and the good is expensive to produce. This situation calls for such a severe taxation

that it induces every shareholder to dodge paying tax.

We now analyze the second-best optimal tax on a case-by-case basis.

Low tax rates: the range of partial tax avoidance

The most interesting case of our analysis occurs when some, but not all, shareholders avoid taxation, that is, $W(\tau) = W_p(\tau)$. Assuming a solution inside the interval $[0, \frac{1}{1-e}]$, the first order-condition for welfare maximization is

$$\begin{aligned} & (v - \delta(1 - e) - p_e(\tau) - (1 - e)D(p_e(\tau), e) + \tau(1 - e)) \frac{\partial D(p_e(\tau), e)}{\partial p_e(\tau)} \\ & + ((1 - e) - \frac{dp_e(\tau)}{d\tau}) D(p_e(\tau), e) - \beta(\tau)(1 - e)D(p_e(\tau), e) \\ & + \frac{d\beta}{d\tau} (p_e(\tau) - c(e) - \tau(1 - e)) D(p_e(\tau), e) = 0. \end{aligned} \quad (1.15)$$

A detailed analysis of welfare maximization is relegated to Appendix 1.8.3. Proposition 3 shows the extent to which tax avoidance affects the optimal tax design in the case where some shareholders still comply with the taxation.

Proposition 3 *The second-best optimal tax with partial avoidance satisfies*

$$\tau = \delta + \frac{p_e(\tau)}{\varepsilon(p_e(\tau))} \left[\frac{-1}{1 - e} + \frac{2(1 - \beta(\tau))}{1 - e} + \frac{2d\beta p_e(\tau) - c(e) - \tau(1 - e)}{d\tau (1 - e)^2} \right]$$

The tax departs from the first-best Pigouvian level (the first term in the right-hand side of the equation in Proposition 3) only if the producer possesses some market power, that is, $\frac{p_e(\tau)}{\varepsilon(p_e(\tau))} > 0$. Hence, the deviation from the Pigouvian level is higher in markets where consumers are less sensitive to price changes. The second term in the right-hand side of equation in Proposition 3 captures Buchanan's correction: the regulator reduces the tax to mitigate the monopolist's tendency to overprice.

The remaining two terms represent two opposite effects of tax avoidance on social welfare: a *free-riding effect* and a *tax base erosion effect*. The shareholders with avoidance costs lower than $\tau(1 - e)$ free-ride on those with higher costs, who thus find it

worthwhile to comply with taxation. The regulator must strengthen the tax to internalize this externality. Therefore, the tax is increased by an amount exactly equal to the term $\frac{p_e(\tau)}{\varepsilon} 2 \frac{1-\beta(\tau)}{1-e}$, which is positive when $\beta(\tau)$ falls below 1. On the other hand, the regulator knows that every tax increase makes fiscal avoidance attractive for some more shareholders, and every lost taxpayer worsens the fiscal imbalance between consumers and shareholders. To offset this welfare loss, the regulator decreases the tax by an amount corresponding to the fourth term in the right hand side of equation in Proposition 3, i.e., $\frac{p_e(\tau)}{\varepsilon} \frac{2(1-\beta(\tau))}{1-e}$. Like the correction for the monopolist's overpricing, the overall correction for tax avoidance, whether positive or negative, is greater when price demand is less elastic.

Subsidies: the range of no avoidance

We now turn to the case where τ is a subsidy, so that social welfare is given by the function $W_n(\tau)$. The shape of this function depends upon three forces appearing in the following derivative:

$$\frac{dW_n(\tau)}{d\tau} = \frac{\partial D(\bullet)}{\partial p} \frac{dp_e}{d\tau} \left[(1-e)\tau - (1-e)\delta + \frac{p_e}{\varepsilon(\bullet)} \right]. \quad (1.16)$$

Raising the tax tends to push the monopoly price up, which both curtails consumption and reinforces the monopolist's tendency to overprice. These two adverse effects on welfare are reflected in, respectively, the first and the third terms in the right-hand side of (1.16), which are negative since $\frac{\partial D(\bullet)}{\partial p} \frac{dp_e}{d\tau} < 0$. It turns out, however, that increasing the emission tax to combat pollution lowers aggregate emissions. This ameliorating effect on welfare is captured by the second positive term in the right-hand side of (1.16). The final outcome ultimately depends on the balance of these conflicting forces. It clearly involves a subsidy when the shape of the welfare function is that depicted in the upper left of Figure 1-2.

High tax rates: the range of full avoidance

Finally, we consider the case where $\frac{1}{(1-e)} \leq \tau \leq \frac{v-c(e)}{1-e}$, so that no shareholder complies with taxation, i.e., $\beta(\tau) = 0$. In that case, the environmental tax is fully passed on to the consumers in a very high price for the polluting good. Social welfare reduces to consumer surplus less the environmental damage. One can check that

$$\frac{dW_f(\tau)}{d\tau} = \frac{\partial D(\bullet)}{\partial p} \frac{dp_e}{d\tau} \left[(1-e)(\tau - \delta) - \frac{p_e}{\varepsilon(\bullet)} \right]. \quad (1.17)$$

Here again, there is no welfare impact of taxation through tax avoidance because the tax base has completely vanished. Taxing polluting emissions boils down to manipulating the consumer price in order to achieve the desired allocation of the good.

In Appendix 1.8.2, we explicitly define τ_n , τ_2 and τ_f as the tax levels that respectively maximize $W_n(\tau)$, $W_p(\tau)$, and $W_f(\tau)$.

Note that τ_n would be the optimal choice for the regulator if there were no tax avoidance in the economy. Hence, τ_n is the traditional tax on emissions under monopoly, as stated by (Buchanan 1969) and later computed by (Lee 1975) and (Barnett 1980). Equating (1.16) to zero yields

$$\tau_n = \delta - \frac{p_e}{(1-e)\varepsilon(\bullet)}. \quad (1.18)$$

Without tax avoidance, the standard result holds in the present setting: the regulator reduces the tax below the Pigouvian level δ to offset the welfare loss due to the monopolistic behavior, which corresponds to $\frac{p_e}{(1-e)\varepsilon(\bullet)}$. By substituting (1.18) into (1.11), we immediately see that τ_n leads to the price that achieves the first-best outcome. This is due to the assumption that the amount of polluting emissions is strictly proportional to the output. As the regulator can mechanically control the output through the tax applied on emissions, this tool is sufficient by itself to correct both the environmental distortion and the monopoly distortion.

We now equate (1.17) to zero and get the following result:

$$\tau_f = \delta + \frac{p_e}{(1-e)\varepsilon(\bullet)}, \quad (1.19)$$

which clearly exceeds τ_n . The second term in the right-hand side of the equation above suggests that when all the shareholders avoid taxation, the regulator is facing externalities other than pollution. We provide a detailed analysis of these externalities in the remainder of the article. For the moment, one synthetic interpretation is that $\frac{p_e}{(1-e)\varepsilon(\bullet)}$ reflects the net cost of the tax avoiders' free-riding, borne by consumers.

To provide an explicit solution for the second-best optimal tax under tax avoidance, we need to divide the parameter configuration into the four regions defined in Table 1.

Region	Boundaries
I	$\delta \leq \frac{v-c(e)}{2(1-e)}$
II	$\frac{v-c(e)}{(1-e)} \geq \frac{1}{4}$ and $\delta \in \left[\frac{v-c(e)}{2(1-e)}, \min \left\{ \frac{24(v-c(e))-1}{32(1-e)}, \frac{(\sqrt{6}-1)(v-c(e))}{2(1-e)} \right\} \right]$ or $\frac{v-c(e)}{(1-e)} \leq \frac{1}{4}$ and $\delta \in \left[\frac{v-c(e)}{2(1-e)}, \frac{v-c(e)+(v-c(e))^2}{2(1-e)} \right]$
III	$\frac{v-c(e)}{(1-e)} \geq \frac{1}{4}$ and
	$\delta \in \left[\frac{24(v-c(e))-1}{32(1-e)}, \min \left\{ \frac{v-c(e)}{1-e}, \frac{5+\sqrt{(3-2(v-c(e)))(2(v-c(e))-3)^2}}{6(1-e)} \right\} \right]$
	or $\frac{v-c(e)}{(1-e)} \leq \frac{1}{4}$ and $\delta \in \left[\frac{v-c(e)+(v-c(e))^2}{2(1-e)}, \frac{v-c(e)}{1-e} \right]$
IV	$\delta \in \left[\max \left\{ \frac{5+\sqrt{(3-2(v-c(e)))(2(v-c(e))-3)^2}}{6(1-e)}, \frac{(\sqrt{6}-1)(v-c(e))}{2(1-e)} \right\}, \frac{v-c(e)}{1-e} \right]$

Table 1.1: Parameter configuration

The four regions are depicted in Figure 1-3. This figure can be read as a map of the regulator's priorities. Region I represents a situation where the environment has a low rank in the agenda of economic priorities because the monopolist is sufficiently clean and efficient. Furthermore, Lemma 1 shows that, in Region I, the unregulated industry is not producing a sufficient amount of the good, from the social standpoint. In contrast, in Region IV, the regulator is very concerned about the environmental damage and, besides the environmental issue, the monopolist has a tendency to produce too much output

given consumer preference for the polluting good. The next lemma compares the welfare levels reached at the different local maxima on a case by case basis.

Lemma 4 *In Region I, $\tau_n \leq 0$ and $W_n(\tau_n) \geq \max \{W_p(\tau_2), W_f(\tau_f)\}$.*

In Region II, $W_n(0) \geq \max \{W_p(\tau_2), W_f(\tau_f)\}$.

In Region III, $W_p(\tau_2) \geq \max \{W_f(\tau_f), W_n(0)\}$.

In Region IV, $W_f(\tau_f) \geq \max \{W_p(\tau_2), W_n(0)\}$.

From this lemma, it is straightforward to characterize explicitly the optimal tax τ_e under the threat of fiscal avoidance, and compare it to Buchanan's tax τ_n .

Proposition 5 *The optimal solution for the regulator is to set τ_e such that:*

(i) τ_e coincides with the subsidy τ_n in Region I;

(ii) $\tau_e = 0 < \tau_n$ in Region II;

(iii) $\tau_e = \tau_2 > \tau_n > 0$ in Region III;

(iv) $\tau_e = \tau_f > \tau_n > 0$ in Region IV.

In Region I, the monopolist is so clean and efficient that the regulator is mainly concerned to correct the monopolist's tendency to overprice and produce too little output from the social standpoint. The optimal policy is to decrease the consumer price through a subsidy in order to boost consumption and mitigate the monopolist's market power. The subsidy is designed in accordance with Buchanan's rule. Clearly, tax avoidance is not an issue in this case. However, the idea that a firm gets paid to pollute may be politically unacceptable (Lee 1975).

In Region II, the environmental issue is more serious and/or the good is more costly to produce than in Region I. Left to itself, the monopolist would produce a too large amount of the polluting good. Observe that this holds true for all parameter values outside Region I: the imperfect competition distortion fails to offset the externality distortion. To combat pollution and correct the monopolist's behavior as well, the regulator, in the absence of tax avoidance, should set the positive tax τ_n on emissions consistent with Buchanan's

rule. Under the threat of tax avoidance, however, the regulator prefers to withhold tax in Region II, worrying about the following chain reaction: a positive tax would have a knock-on effect on tax avoidance, creating a shortfall in tax revenue that would, in turn, call for a further increase in the tax. This chain reaction would create a welfare loss relative to the zero-tax decision. To some extent, the optimal policy in Region II boils down to letting the monopolist regulate the market for the regulator. The internalization of the environmental externality is passed on to consumers through the monopoly price premium they have to pay for the polluting good. Tax avoidance is an issue in that it is a deterring threat directed against taxation.

In Regions III and IV, the severity of the environmental damage as well as significant production costs require a positive tax τ_e , which exceeds Buchanan's tax. In Region III, the tax $\tau_e = \tau_2$ induces a number of shareholders with low costs of tax avoidance to avoid taxation. Not all of the shareholders avoid taxation, but those who do exert a negative externality on the rest of society in terms of lost fiscal revenue. To offset this welfare loss, the regulator can only hit the remaining taxpayers harder than if there were no tax avoidance, through a tax increase that also inflates the consumer price. The optimal solution strikes the balance between the need to collect tax yields and the dual correction for the pollution and the monopolistic behavior. In Region IV, taxation is so severe that the regulator completely loses the tax base, thereby losing the fiscal revenue to correct for distortions in the economy. The regulator leaves the whole burden of the tax on the consumers through the price at which they purchase the good. All the regulatory corrections rely on the manipulation of the monopoly price through taxation. The regulator chooses the tax τ_f that raises the monopoly price up to the level at which the consumers' purchase decisions fully internalize the environmental externality.

Figure 1-4 illustrates how the optimal tax regimes change with the severity of the environmental damage and the firms' efficiency. The bold curves plot τ_e as a function of $(1 - e)\delta$, whereas the dashed line depicts τ_n as a function of $(1 - e)\delta$. The three cases are drawn for low, intermediate and high MSVs of the good. The function τ_e remains flat

at level zero, below τ_n , reflecting that, to prevent tax avoidance, the regulator refrains from taxing emissions. At some critical level of the MSC, however, τ_e jumps above τ_n to correct for the free-riding of the tax avoiders.

1.4 The two-part tax schedule

We now assume that the regulator is not restricted to linear taxation, as is traditionally the case. Instead, we let the regulator use the affine (but nonlinear) tax schedule $\tau q + T$, where τ is a unit tax for the firm's emission and T is a lump-sum tax T — an “entry-fee” into the market — that the firm must pay regardless of the number of units of the polluting emissions.

Social welfare is now

$$W(\tau, T) = \int_0^{D(p_e, e)} [v - (1 - e)x - \delta(1 - e) - p_e(\tau) + \tau(1 - e)] dx + T + \beta(\tau) \pi_e(p_e(\tau), e), \quad (1.20)$$

where the monopoly profit is $\pi_e(p_e(\tau)) = (p_e(\tau) - c(e) - \tau(1 - e))D(p_e(\tau), e) - T$. Substituting this expression into (1.20), we have

$$W(\tau, T) = [v - p_e(\tau) + (\tau - \delta)(1 - e) + \beta(\tau)(p_e(\tau) - c(e) - \tau(1 - e))] D(p_e(\tau), e) - \frac{(1 - e) D(p_e(\tau), e)^2}{2} + (1 - \beta(\tau)) T \quad (1.21)$$

The welfare maximization problem of the regulator is

$$\begin{aligned} & \max_{\tau, T} W(\tau, T) \\ & \text{s. t. } \pi_e(p_e(\tau)) \geq 0 \end{aligned}$$

The participation constraint in the regulator's optimization program requires that the firm gets no rent. This constraint is binding at the optimal solution since the regulator

wants T to be as large as possible:

$$(p_e(\tau) - c(e) - \tau(1 - e))D(p_e(\tau), e) = T \quad (1.22)$$

We substitute the expression for T into (1.21) and use (1.12). This yields the following reduced form

$$W(\tau) = [v - c(e) - \delta(1 - e)] D(p_e(\tau), e) - \frac{(1 - e)D(p_e(\tau), e)^2}{2} \quad (1.23)$$

The first-order condition for welfare maximization is

$$\frac{\partial D(\bullet)}{\partial p} \frac{dp_e}{d\tau} \left[(1 - e)\tau - (1 - e)\delta + \frac{p_e}{\varepsilon(\bullet)} \right] = 0 \quad (1.24)$$

From (1.18), we can see that τ_n solves (1.24).

Proposition 6 *The optimal two-part tax schedule entails*

- (i) *the unit tax τ_n ,*
- (ii) *and the lump-sum tax $T = (p_e(\tau_n) - c(e) - \tau_n(1 - e))D(p_e(\tau_n), e)$.*

As a result, the two-part tax schedule can solve the problem of tax avoidance. The lump-sum tax enables the regulator to capture the whole profit of the polluting firm, thereby eliminating any incentive on the part of the shareholders to avoid taxation. The regulator can then set the unit tax in accordance with Buchanan's rule to correct the two remaining distortions caused by pollution and market power. In the present setting, this combination helps the regulator achieve the first-best outcome.

1.5 The example of BHPP

The following example is one among others⁴ that may illustrate the reluctance of the environmental regulator to correct for the environmental externality presumably because

⁴See also (Mambondiyani 2012) and (The Economist 2013).

of tax avoidance. In the Far Eastern region of Krasnoyarsk, the Russian government has allowed Boges Limited to operate a hydro power station called the Boguchany Hydroelectric Power Plant (BHPP). This large business enjoys a natural monopoly position. The construction of the dam reservoir has been largely deplored as a threat to the environment. The reservoir floods villages, forests, agricultural land, meadows and pastures, bringing about significant changes in the geographical landscape. According to (Jagus and Rzetala 2013), the main environmental hazards stem from rising water levels which alter the landform, raising the ground water table, and compromising the water quality. The flooding of lands and forests affects the local climate, which in turn leads to a loss of natural ecosystems and habitats. On the other hand, the government aims to develop and urbanize the region, increasing living standards. The commission of BHPP should collect 2.4 billion rubles (84 million USD) of tax revenues in the public budget and provide at least ten thousand jobs in the region (Khotuleva and al. 2006, p. 16). However, more than 95% of the shareholders of Boges Ltd. are registered in Cyprus—a well-known tax haven (Baranova 2013). In what follows, we provide a detailed analysis of this real-world situation in the light of our findings.

The table in Figure 1-5 displays the annual report of Boges Ltd. for the year 2012⁵. It represents the main indicators of economic activity of the firm. The highlighted row gives a piece of evidence that although the Russian law on water use, water and air pollution, land-retirement and such, provides for the existence of enforceable taxes, Boges Ltd. has paid no taxes, whether revenues be positive in 2011 or negative in 2010 and 2012. This is the actual outcome corresponding to Region II of Figure 1-3.

Given the large number of Boges Ltd. shareholders registered in Cyprus, the regulator is highly exposed to fiscal avoidance. Compared to the overwhelming task of fostering economic growth in the region of Krasnoyarsk, environmental issues are at the bottom of the regulator's agenda. The government has still not achieved the construction of an

⁵The original Russian version can be consulted at: http://www.boges.ru/files/fin_otchet/2012/Otchet_2012_2.pdf, page 33.

aluminum plant which is expected to become the major client of the dam and one of the main employers in the region. In the meantime, Boges Ltd. is producing in excess of the environmental requirement in the region— this situation fits the parameter configuration delimited by $(1 - e) \delta > \frac{v-c(e)}{2}$ in Figure 1-3. On the basis of (Shishikin and Sirotsky 2009), (Baranova 2013) claims that “the damage caused by the power station to the area in terms of forest, land, water and fishing resources, as well as birds and animals, will amount to 4.5 billion rubles (£90 million)— that is assuming an outflow head of only 185 metres”. Besides, the damage from the project also encompasses the loss of local cultural amenities such as archeological monuments, wooden architecture, nonmaterial heritage like local dialects, songs, and customs (Khotuleva and al. 2007, p. 428). In this context, the monopolist’s tendency to underproduce can hardly offset the distortion due to the various externalities caused by the dam, so that a sound environmental regulation calls for a positive tax along Buchanan’s line. However, with no device to ensure tax compliance, the regulator has no leeway: a positive tax would exacerbate the free-riding of the tax avoiders without yielding enough revenue to outweigh the further welfare loss. As a result, the regulator finds it optimal to set a zero tax on pollution.

1.6 Discussion on the modelling choice of avoidance function

In the present version, we have chosen to model tax avoidance subsequent to an imposition of environmental taxation as an internal decision of the firm which is *exogenous* to our analysis. There is no or little specification for the mechanism that the avoidance decision may take. Indeed, different avoidance schemes may come to mind: it can be profit shifting, relocation of production facilities to jurisdictions with a laxer regulation; it can be green washing, or political lobbying against the regulation among others.

It is common knowledge that taxation in general gives rise to tax optimization and may entail non-compliance. Environmental taxation is certainly no exception. Asym-

metric information being an inherent feature of environmental performance, in which quality is unobservable and hardly verifiable, renders the enforcement of environmental policy and its monitoring problematic. In this analysis, we have proposed the simplest way to frame the idea that higher tax rates give taxpayers greater incentives to avoid liability. Therefore we let the firm be immediately responsive to the level of tax, adjusting accordingly her compliance levels. Hence the assumption that firm's shareholders are heterogenous in the cost of tax avoidance.

Certainly one may argue that dividends are paid on the after-tax profit, and shareholders have little interest in or grasp of how to influence a firm's compliance behavior. Yet, a firm has a complex hierarchy for decision-making and firm's management is entrusted to executives who are generously rewarded to maintain high financial performance. Hence, we abstract from the mechanism of avoidance decision assuming it comes from a black box.

Ultimately, the incidents of successful global environmental policy are few. The EU emission trading system struggles to maintain a 'meaningful' carbon price that would reflect its social cost. Yet, it still varies around 7 € per ton⁶. During the past decade the allowances were in oversupply and nevertheless often allocated freely⁷. An attempt to introduce an eco-tax in France under the Grenelle law has turned out to be a complete failure. It has cost taxpayers the construction of the infrastructure that has never been in use, plus there are penalties for violation of contract terms to the firm commissioned for the project.

Thus we believe that a firm with market power and an international infrastructure such as a multinational can and will find ways to reduce its environmental liabilities. The micro foundation of avoidance decision is, however, beyond the scope of this paper and hence is left for a future research.

⁶ "EU Market: EU carbon prices again recover from sub- €6.80 levels to post small weekly loss", <https://carbon-pulse.com/category/eu-ets/>.

⁷ "EU Emissions Trading System", <http://carbonmarketwatch.org/category/eu-climate-policy/eu-ets/>.

1.7 Conclusion

‘Free-riding on environmental taxation’ implies that the monopolist takes advantage of consumers’ willingness to pay for higher environmental quality. Yet, the firm doesn’t entirely carry out her fiscal duties.

If the purpose of environmental taxation is to induce a firm to consider the full set of consequences of polluting emissions, the tax should also internalize the externality caused by those shareholders who avoid taxation. The novelty of our approach is to allow the environmental regulator to endogenize tax avoidance and examine how this framework affects traditional policy recommendations. In a monopoly setting without allowing for tax avoidance, the standard environmental taxation follows Buchanan’s rule: as the monopoly distortion partly outweighs the externality distortion, the tax on polluting emissions must be set below the Pigouvian level; the tax cut resulting from the need to correct for the firms’ market power may be so sharp that the optimal policy imposes to subsidize the product when the monopolist is significantly clean and the good is cheap to produce.

Outside these circumstances, we find that tax avoidance biases the second-best environmental tax away from Buchanan’s tax in two opposite directions.

First, in situations where Buchanan’s tax would be positive, it may happen that the fear of triggering tax avoidance compels the regulator to refrain from taxing the polluting emissions. This occurs when the monopolist is moderately clean and/or moderately efficient. In that case, the revenue raised from a positive tax would not fully offset the welfare loss produced by those shareholders who avoid taxation. Then, tax avoidance proves to be a deterrent threat against taxation.

Second, when the monopolist is significantly dirty and moderately efficient, the regulator must internalize the free-riding of tax avoiders by taxing emissions more severely than if there were no tax avoidance. The shareholders who comply with taxation pay the bill for the free-riding of those who bypass taxation. In the extreme case where all the shareholders avoid taxation, the tax increase inflates the monopoly price so that the whole

burden of internalizing the environmental externality is passed on to the consumers.

Ultimately, we show that the problem of tax avoidance can be solved by the combination of a lump-sum tax that captures the whole profit of the polluting monopolist and Buchanan's tax on emissions.

The policy implications of our findings are rather grim. When the environmental regulator is restricted to linear taxation, tax avoidance is a serious stone in the regulator's shoe, forcing the regulator to be either impotent or unfair. The regulator proves impotent when the threat of tax avoidance deters the regulator from taxing emissions. In this case, the best policy is to let the monopolist charge the consumers a price that under-internalizes the environmental externality. On the other hand, the regulator proves unfair when tax avoidance forces the regulator either to overtax those who comply with taxation, or to drastically inflate the monopoly price with a tax that everyone avoids. In both cases, one objective is to internalize the externality caused by the free-riding of the tax avoiders. However, unlike the environmental externality, those who pay the bill for the free-riding are not those who generate the externality. This may be seen as politically unacceptable both by taxpayers and consumers.

The two-part tax schedule seems, on paper, an attractive solution to the problem of tax avoidance. Nevertheless, the literature on environmental taxation usually considers that lump-sum taxes and transfers are not available in practice (Bovenberg and van der Ploeg 1994). We have also demonstrated how tax avoidance makes it difficult to design a linear tax on polluting emissions, which finally argues in favour of implementing specific enforcement measures against tax avoidance.

1.8 Appendix

1.8.1 Laffer curve

Consider first the case where all the shareholders comply with taxation, that is, $\beta(\tau) = 1$ for all τ . Using (1.3) and (1.12), the fiscal revenue with respect to τ is given by

$$\begin{aligned} R_n(\tau) &= \tau(1-e)D(p_e(\tau)) \\ &= \frac{\tau}{2}(v-c(e)-\tau(1-e)) \end{aligned} \quad (1.25)$$

This function is an inversely u-shaped parabola in τ , which takes zero value at $\tau = 0$ and $\tau = \frac{v-c(e)}{1-e}$, and which reaches a maximum at $\hat{\tau}_n = \frac{v-c(e)}{2(1-e)}$.

We now take tax avoidance into account and obtain the revenue function $R(\tau)$ given by (1.13). For all $\tau \in \left[0, \frac{1}{1-e}\right]$, the first derivative is

$$\frac{\partial R(\tau)}{\partial \tau} = \frac{1}{2} (3\tau^2(1-e)^2 - 2(v-c(e)+1)\tau(1-e) + v-c(e)). \quad (1.26)$$

The first-order condition yields only one admissible extremum inside $\left[0, \frac{1}{1-e}\right]$, namely $\hat{\tau} = \frac{v-c(e)+1-\sqrt{(v-c(e))^2-(v-c(e))+1}}{3(1-e)}$. One can check that the upper solution of equation $\frac{\partial R(\tau)}{\partial \tau} = 0$ is $\frac{v-c(e)+1+\sqrt{(v-c(e))^2-(v-c(e))+1}}{3(1-e)}$, which exceeds $\frac{1}{1-e}$.

The second derivative is

$$\frac{\partial^2 R(\tau)}{\partial \tau^2} = 3\tau(1-e) - (v-c(e)) - 1, \quad (1.27)$$

which takes the following value at τ_2

$$\frac{\partial^2 R(\tau)}{\partial \tau^2} \Big|_{\hat{\tau}} = -\sqrt{(v-c(e))^2 - (v-c(e)) + 1} < 0. \quad (1.28)$$

Thus, $\hat{\tau}$ is a maximum. Straightforward calculations show that the maximum of $R(\tau)$ is always lower than that of $R_n(\tau)$, that is, $\hat{\tau} < \frac{v-c(e)}{2(1-e)}$.

1.8.2 Proof of Lemma 2

The proportion of shareholders who comply with taxation depends on the tax level. As a result, the social welfare function can be decomposed as follows:

- If $\tau \leq 0$, no shareholder avoids taxation, hence $\beta(\tau) = 1$. From (1.10), $W(\tau)$ is then given by

$$W_n(\tau) = (1 - e) \left[3D(p_e(\tau), e)^2 / 2 + (\tau - \delta) D(p_e(\tau), e) \right], \quad (1.29)$$

which reaches a maximum at $\tau_n = 2\delta - \frac{v-c(e)}{1-e}$, so that $W_n(\tau_n) = \frac{(v-c(e)-\delta(1-e))^2}{2(1-e)}$.

- If $0 \leq \tau \leq \frac{1}{1-e}$, the proportion of shareholders who comply with taxation is $\beta(\tau) = 1 - \tau(1 - e)$. From (1.10), $W(\tau)$ is then given by

$$W_p(\tau) = (1 - e) \left[\left(\frac{3}{2} - \tau(1 - e) \right) D(p_e(\tau), e)^2 + (\tau - \delta) D(p_e(\tau), e) \right], \quad (1.30)$$

with a minimum at $\tau_1 = \frac{4(v-c(e))-1-\sqrt{4(v-c(e))^2-20(v-c(e))+1+24\delta(1-e)}}{6(1-e)}$ and a maximum at $\tau_2 = \frac{4(v-c(e))-1+\sqrt{4(v-c(e))^2-20(v-c(e))+1+24\delta(1-e)}}{6(1-e)}$, provided that the discriminant $\Delta_p = 4(v - c(e))^2 - 20(v - c(e)) + 1 + 24\delta(1 - e) \geq 0$; otherwise, $W_p(\tau)$ is a decreasing function of τ . Notice that $\tau_1 \times \tau_2 \geq 0$ if and only if $\delta \leq \frac{v-c(e)+(v-c(e))^2}{2(1-e)}$. Moreover, if $\frac{v-c(e)}{1-e} \geq \frac{1}{4}$, then $\tau_2 \geq 0$, and if $\frac{v-c(e)}{1-e} \leq \frac{1}{4}$, then $\tau_1 \leq 0$. Thus, we have

$$\begin{aligned} - \tau_2 &\geq 0 \text{ for all } \delta \geq \frac{v-c(e)+(v-c(e))^2}{2(1-e)} \text{ or } \frac{v-c(e)}{1-e} \geq \frac{1}{4}, \\ - \tau_1 &\leq 0 \text{ for all } \delta \geq \frac{v-c(e)+(v-c(e))^2}{2(1-e)} \text{ or } \frac{v-c(e)}{1-e} \leq \frac{1}{4}. \end{aligned}$$

- If $\frac{1}{1-e} \leq \tau \leq \frac{v-c(e)}{1-e}$, no shareholder complies with taxation, hence $\beta(\tau) = 0$. From (1.10), $W(\tau)$ is then given by

$$W_f(\tau) = (1 - e) \left[\frac{D(p_e(\tau), e)^2}{2} + (\tau - \delta) D(p_e(\tau), e) \right], \quad (1.31)$$

which reaches a maximum at $\tau_f = \frac{2}{3}\delta + \frac{v-c(e)}{3(1-e)}$, so that $W_f(\tau_f) = \frac{(v-c(e)-\delta(1-e))^2}{6(1-e)}$.

1.8.3 First-order condition for welfare maximization

Using the fact that $(1-e)D(p_e(\tau), e) = v - p_e(\tau)$, Equation (1.15) turns into

$$\begin{aligned} (\tau - \delta)(1-e) \frac{\partial D(p_e(\tau), e)}{\partial p_e(\tau)} \frac{dp_e(\tau)}{d\tau} - \frac{dp_e(\tau)}{d\tau} D(p_e(\tau), e) + (1-\beta(\tau)) \\ (1-e)D(p_e(\tau), e) + \frac{d\beta(\tau)}{d\tau} [p_e(\tau) - c(e) - \tau(1-e)] D(p_e(\tau), e) = 0. \end{aligned} \quad (1.32)$$

Substituting $\varepsilon(p_e(\tau)) = -\frac{\partial D(p_e(\tau), e)}{\partial p_e(\tau)} \frac{p_e(\tau)}{D(p_e(\tau), e)}$ into the left-hand side above, we have

$$\begin{aligned} \tau - \delta + \frac{p_e(\tau)}{(1-e)\varepsilon(\cdot)} - (1-\beta(\tau)) \frac{p_e(\tau)}{\frac{dp_e(\tau)}{d\tau}\varepsilon(\cdot)} - \frac{d\beta}{d\tau} (p_e(\tau) - c(e)) \\ - \tau(1-e) \frac{p_e(\tau)}{(1-e)\frac{dp_e(\tau)}{d\tau}\varepsilon(\cdot)} = 0, \end{aligned} \quad (1.33)$$

which reduces to the expression from Proposition 3 after substituting $\frac{1-e}{2}$ for $\frac{dp_e(\tau)}{d\tau}$.

1.8.4 Proof of Lemma 4

1. We first concentrate on Region I, where $\delta \leq \frac{v-c(e)}{2(1-e)}$. The inequality $\tau_n \leq 0$ is equivalent to $\delta \leq \frac{v-c(e)}{2(1-e)}$. It follows that τ_n is a local maximum for this parameter configuration. Furthermore, two cases can be distinguished, depending on the sign of Δ_p . First, if $\Delta_p < 0$, then $W_p(\tau)$ is decreasing on the interval $[0, \frac{1}{1-e}]$, and τ_f is also a local maximum provided that $\tau_f > \frac{1}{1-e}$, which amounts to $\delta > \frac{3-(v-c(e))}{2(1-e)}$. Nevertheless, it is straightforward that $W_n(\tau_n) > W_f(\tau_f)$ always holds, hence τ_n is always more beneficial than τ_f from the social standpoint. The second case corresponds to parameter values such that $\Delta_p \geq 0$, or equivalently, $\delta \leq \frac{-4(v-c(e))^2 + 20(v-c(e)) - 1}{24(1-e)}$. Then, τ_2 may be another local maximum because $\tau_2 \leq \frac{1}{1-e}$ when $\delta \leq \frac{v-c(e)}{2(1-e)}$. Indeed, for all parameter values in Region I, $\delta \leq \frac{(v-c(e))^2 - 3(v-c(e)) + 4}{2(1-e)}$, which is equivalent to $\tau_2 \leq \frac{1}{1-e}$ and less restrictive than $\delta \leq \frac{v-c(e)}{2(1-e)}$. As previously seen,

a further condition for τ_2 to be a local maximum is that $\delta \geq \frac{v-c(e)+(v-c(e))^2}{2(1-e)}$ or $\frac{v-c(e)}{(1-e)} \geq \frac{1}{4}$. After some calculations, we find that $W_n(\tau_n) \leq W_p(\tau_2)$ if and only if $\delta \geq \frac{v-c(e)}{1-e}$ or $\frac{1}{54(1-e)} \left(36(v-c(e)) - 1 - \sqrt{(1-6(v-c(e)))(1-6(v-c(e)))^2} \right) \leq \delta \leq \frac{1}{54(1-e)} \left(36(v-c(e)) - 1 + \sqrt{(1-6(v-c(e)))(1-6(v-c(e)))^2} \right)$. It turns out that these parameter values are outside Region I, hence $W_n(\tau_n) > W_p(\tau_2)$ holds in this parameter configuration.

2. We now turn to Region II. If $\delta \geq \frac{v-c(e)}{2(1-e)}$, then $W_n(\tau)$ is increasing for negative values of τ up to zero, which makes $\tau = 0$ a local maximum provided that $W_p(\tau)$ decreases at this value, which amounts to $\tau_1 \geq 0$. In addition, τ_2 may also be a local maximum provided that, first, $\Delta_p \geq 0$ (which guarantees the existence of τ_2), second, $\delta \geq \frac{v-c(e)+(v-c(e))^2}{2(1-e)}$ or $\frac{v-c(e)}{(1-e)} \geq \frac{1}{4}$ (in which case $\tau_2 \geq 0$), and third, $\tau_2 \leq \frac{1}{1-e}$ (or, equivalently, $\delta \leq \frac{(v-c(e))^2-3(v-c(e))+4}{2(1-e)}$) as previously mentioned. Furthermore, τ_f happens to be a local maximum too when $\tau_f \geq \frac{1}{1-e}$ (i.e., for parameter values such that $\delta \geq \frac{3-(v-c(e))}{2(1-e)}$).

Let us first assume that $\frac{v-c(e)}{(1-e)} \geq \frac{1}{4}$ and $\delta \in \left[\frac{v-c(e)}{2(1-e)}, \min \left\{ \frac{24(v-c(e))-1}{32(1-e)}, \frac{(\sqrt{6}-1)(v-c(e))}{2(1-e)} \right\} \right]$. Assume $\Delta_p \geq 0$ so that τ_2 does exist. As $\frac{v-c(e)}{(1-e)} \geq \frac{1}{4}$, we know that $\tau_2 \geq 0$, and moreover, $\tau_2 \leq \frac{1}{1-e}$ only if $\delta \leq \frac{(v-c(e))^2-3(v-c(e))+4}{2(1-e)}$. Assuming this to be the case, τ_2 is a local maximum. In addition, $\tau_1 \geq 0$ because $\delta \leq \frac{v-c(e)+(v-c(e))^2}{2(1-e)}$ is less restrictive than $\delta \leq \min \left\{ \frac{24(v-c(e))-1}{32(1-e)}, \frac{(\sqrt{6}-1)(v-c(e))}{2(1-e)} \right\}$. Thus, $\tau = 0$ is a local maximum too, and routine calculations show that $W_n(0) \geq W_f(\tau_2)$ when $\delta \leq \frac{24(v-c(e))-1}{32(1-e)} (< \frac{v-c(e)}{1-e})$. Further calculations yield that $W_n(0) \geq W_f(\tau_f)$ when $\delta \leq \frac{(\sqrt{6}-1)(v-c(e))}{2(1-e)} (< \frac{v-c(e)}{1-e})$. As a result, $W_n(0) \geq \max \{W_p(\tau_2), W_f(\tau_f)\}$ for all parameter values in this configuration.

Examine now the part of Region II where $\frac{v-c(e)}{(1-e)} \leq \frac{1}{4}$ and $\delta \in \left[\frac{v-c(e)}{2(1-e)}, \frac{v-c(e)+(v-c(e))^2}{2(1-e)} \right]$. In this parameter configuration, $\delta < \frac{3-(v-c(e))}{2(1-e)}$, and so $W_f(\tau)$ is a decreasing function of τ on the interval $\left[\frac{1}{1-e}, \frac{v-c(e)}{1-e} \right]$. Moreover, we know that $\tau_2 \leq 0$ when $\delta \leq \frac{v-c(e)+(v-c(e))^2}{2(1-e)}$, hence $W_p(\tau)$ is also decreasing on $\left[0, \frac{1}{1-e} \right]$. Thus, $\tau = 0$ is a global

maximum in this parameter configuration.

We can conclude that $W_n(0) \geq \max \{W_p(\tau_2), W_f(\tau_f)\}$ for parameter values inside Region II.

3. Consider now Region III. One can check that $\Delta_p > 0$ for these parameter values, because $\frac{-4(v-c(e))^2+20(v-c(e))-1}{24(1-e)} < \frac{24(v-c(e))-1}{32(1-e)} < \frac{v-c(e)+(v-c(e))^2}{2(1-e)}$. It follows that τ_2 exists and is positive when either $\frac{v-c(e)}{(1-e)} \geq \frac{1}{4}$ or $\frac{v-c(e)}{(1-e)} \leq \frac{1}{4}$ and $\delta \geq \frac{v-c(e)+(v-c(e))^2}{2(1-e)}$. Moreover, it turns out that $\tau_2 < \frac{1}{1-e}$ because, first, when $\frac{v-c(e)}{(1-e)} \geq \frac{1}{4}$, we have $\frac{5+\sqrt{(3-2(v-c(e)))(2(v-c(e))-3)^2}}{6(1-e)} < \frac{(v-c(e))^2-3(v-c(e))+4}{2(1-e)}$, and second, when $\frac{v-c(e)}{(1-e)} \leq \frac{1}{4}$, we have $\frac{v-c(e)}{(1-e)} < \frac{(v-c(e))^2-3(v-c(e))+4}{2(1-e)}$. Hence, τ_2 is a local maximum.

Furthermore, $\tau = 0$ may be a local maximum too, because $\frac{v-c(e)}{2(1-e)} < \delta$ holds, and so $\tau_n > 0$. Indeed, one can check, first, that $\frac{v-c(e)}{2(1-e)} < \frac{24(v-c(e))-1}{32(1-e)}$ when $\frac{v-c(e)}{(1-e)} \geq \frac{1}{4}$, and second, that $\frac{v-c(e)}{2(1-e)} < \frac{v-c(e)+(v-c(e))^2}{2(1-e)}$ when $\frac{v-c(e)}{(1-e)} \leq \frac{1}{4}$, thereby implying $\frac{v-c(e)}{2(1-e)} < \delta$. However, in the case where $\frac{v-c(e)}{(1-e)} \leq \frac{1}{4}$ or $\delta \geq \frac{v-c(e)+(v-c(e))^2}{2(1-e)}$, we know that $\tau_1 \leq 0$, meaning that $W_p(\tau)$ is increasing at $\tau = 0$, so this tax is not a local maximum.

In addition, τ_f happens to be a local maximum when $\tau_f \geq \frac{1}{1-e} (\delta \geq \frac{3-(v-c(e))}{2(1-e)})$.

Assuming $\frac{v-c(e)}{(1-e)} > \frac{1}{4}$ and $\delta < \frac{v-c(e)+(v-c(e))^2}{2(1-e)}$, so that $\tau = 0$ is actually a local maximum, routine calculations show that $W_n(0) \leq W_p(\tau_2)$ for all δ inside $\left[\frac{24(v-c(e))-1}{32(1-e)}, \frac{(v-c(e))^2+(v-c(e))}{2(1-e)} \right]$. Finally, one can check that parameter values inside Region III also belong to the interval

$$\left[\frac{5-\sqrt{(3-2(v-c(e)))(2(v-c(e))-3)^2}}{6(1-e)}, \frac{5+\sqrt{(3-2(v-c(e)))(2(v-c(e))-3)^2}}{6(1-e)} \right]$$

for which $W_p(\tau_2) \geq W_f(\tau_f)$.

We conclude that $W_p(\tau_2) \geq \max \{W_f(\tau_f), W_n(0)\}$ in Region III. Moreover, straightforward calculations yield that $\tau_2 > \tau_n$ for all δ inside $\left[\frac{2(v-c(e))}{3(1-e)}, \frac{v-c(e)}{(1-e)} \right]$, which includes all the parameter values inside Region III unless $v - c(e) \in (0; \frac{1}{3})$.

4. We finally turn to Region IV. All $\delta > \max \left\{ \frac{5+\sqrt{(3-2(v-c(e)))(2(v-c(e))-3)^2}}{6(1-e)}, \frac{(\sqrt{6}-1)(v-c(e))}{2(1-e)} \right\}$ is also greater than $\frac{3-(v-c(e))}{2(1-e)}$. This inequality guarantees that $\tau_f > \frac{1}{1-e}$, mean-

ing that τ_f is a local maximum. In the same parameter configuration, one can check that $\Delta_p \geq 0$, hence τ_2 exists, and moreover τ_2 is positive since $\frac{v-c(e)}{(1-e)} > \frac{1}{4}$. It follows that τ_2 is a local maximum too, unless $\tau_2 > \frac{1}{1-e}$, which amounts to $\delta > \frac{(v-c(e))^2-3(v-c(e))+4}{2(1-e)}$. Suppose this is the case. Then $\tau = 0$ is a local maximum because, first, $\delta \geq \frac{v-c(e)}{2(1-e)}(\tau_1 \geq 0)$, and second, $\frac{v-c(e)}{(1-e)} > \frac{1}{4}$ and $\delta < \frac{v-c(e)+(v-c(e))^2}{2(1-e)}(\tau_1 > 0)$ for parameter values inside Region IV. In this case, $\delta \geq \frac{(\sqrt{6}-1)(v-c(e))}{2(1-e)}$ implies that $W_f(\tau_f) \geq W_n(0)$. Otherwise, $\tau_2 \leq \frac{1}{1-e}$, hence τ_2 is a local maximum and, for all δ inside $\left[\frac{5+\sqrt{(3-2(v-c(e)))(2(v-c(e))-3)^2}}{6(1-e)}, \frac{v-c(e)}{1-e} \right]$, we have $W_f(\tau_f) \geq W_p(\tau_2)$. To sum up, $W_f(\tau_f) \geq \max\{W_p(\tau_2), W_n(0)\}$ in Region IV.

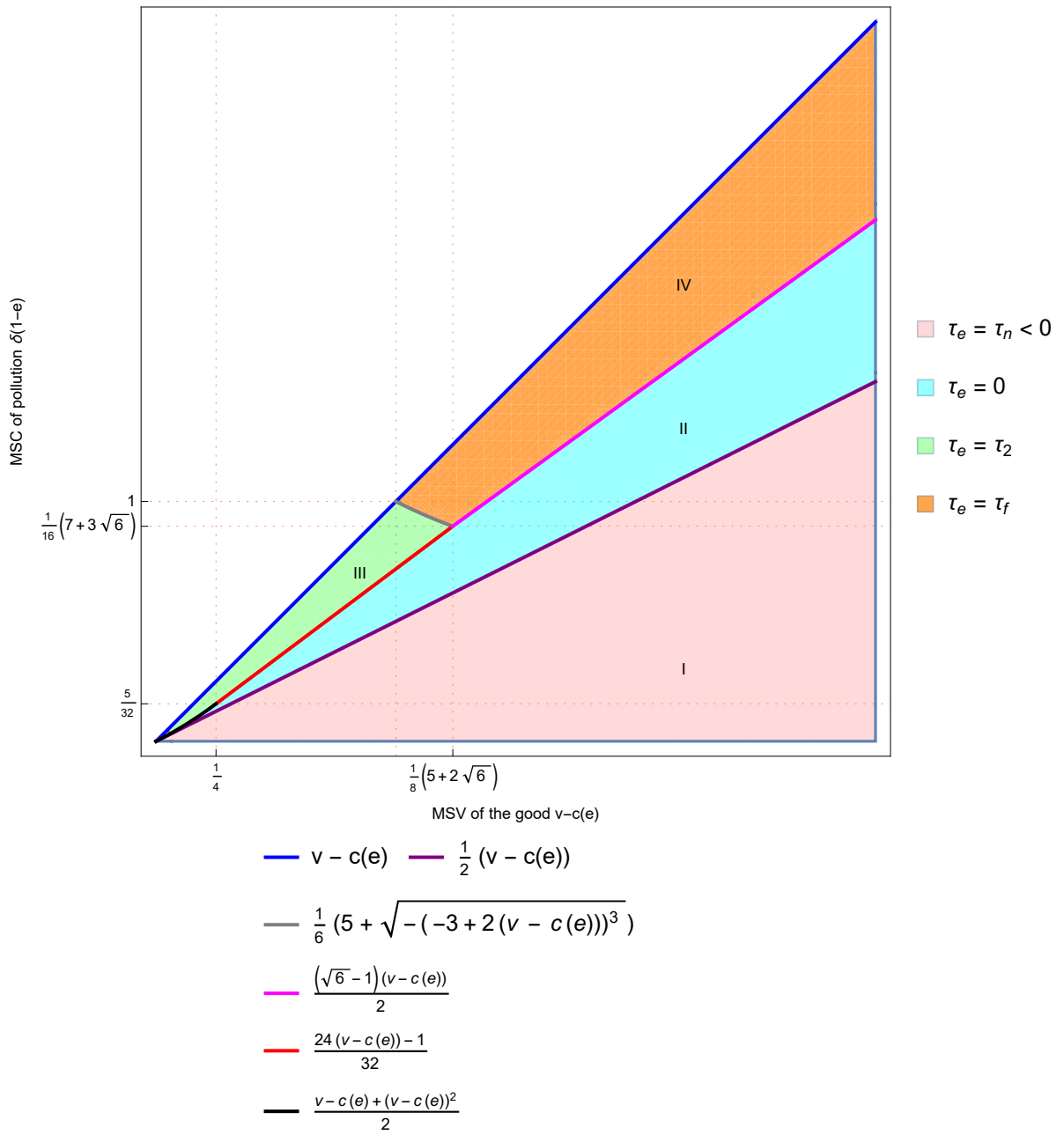


Figure 1-3: Optimal taxation by zones

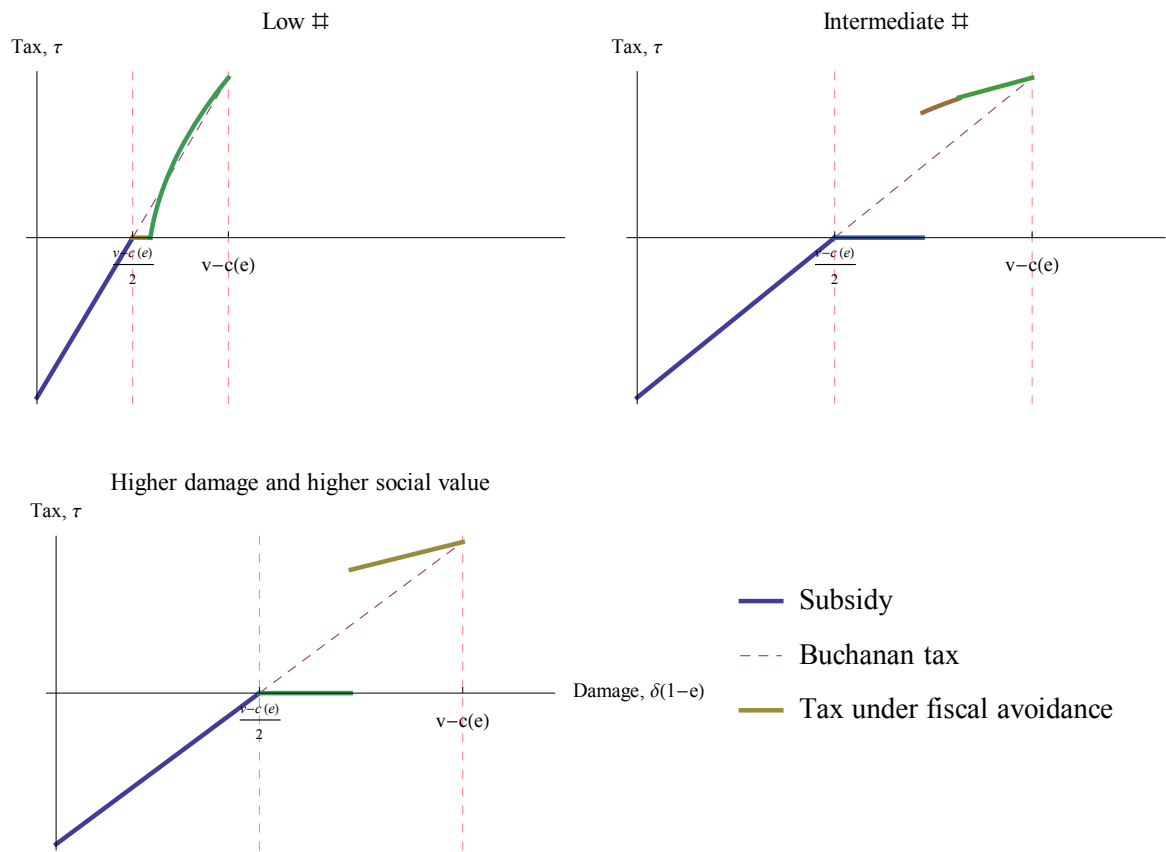


Figure 1-4: Comparison between Buchanan's and optimal taxation with avoidance

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4. Economy and Finance

4.1. Main financial and economic indicators

Table 15 (in thousands of rubles)

Number	Indicator	2010	2011	2012	The growth rate, (4/5)%
(1)	(2)	(3)	(4)	(5)	(6)
1	Revenues from sales	2 148 547	2 029 271	1 412 899	70%
2	Prime cost	-2 069 294	-1 938 693	-1 573 157	81%
3	Gain / loss from sales	79 253	90 578	-160 258	-277%
4	Other income	38 353	678 756	117 412	17%
5	Other expenses	-145 788	-496 684	-485 919	98%
6	Profit before taxation	-28 182	272 650	-528 765	-194%
7	Current income tax	0	0	0	0%
8	Change in deferred tax liabilities	-181 428	-115 496	-305 165	264%
9	Change in deferred tax assets	105 372	117 348	382 143	326%
10	Other / miscellaneous	37 786	-1 711	-121	7%
11	Net profit	-66 452	272 791	-451 908	-266%

Figure 1-5: Boges Ltd. pays zero tax on current income

Part II

Environmental regulation under asymmetric information

Chapter 2

Environmental regulation with price signaling

The article studies how incomplete information affects the optimal second-best environmental tax in a monopoly setting. We endogenize the pollution tax to analyze its impact on social welfare. We show that the optimal tax must be set below the level required for a polluting monopoly under complete information. The tax is composed of three elements to correct corresponding market distortions: the Pigouvain standard to internalize the pollution externality, an adjustment of monopolistic restraint of output and an element to account for information asymmetry. As the tax enters the product's price, consumers' expectations of high environmental quality determine the value of the clean (non-polluting) product, the trade of which is inevitably reduced by the pollution tax. Hence, the regulator who places a corresponding value on the clean variety, scales down the optimal tax level. While under pooling, the pollution tax equalizes the expected social value to the expected social cost of the product, it is no longer attainable under separating equilibrium. With weak tax, the expected product price exceeds its expected social cost and vice versa with severe tax.

Keywords: Signaling, Environmental Regulation, Information and Environmental Product Quality

JEL Code: D82, L15, Q5

Résumé du chapitre 2

Le chapitre 2 étudie l'impact de l'asymétrie d'information sur la taxe environnementale du second rang.

L'intérêt principal du chapitre est d'endogénéiser la taxe afin d'évaluer son impact sur le bien-être social. Le cadre comprend un cas d'industrie en concurrence imparfaite et une qualité environnementale inobservable. Un monopole utilise le prix pour signaler que son produit propre (qualité haute) ne génère pas de pollution. Pour éviter qu'un producteur de type sale (qualité faible) ne vende un produit polluant au même prix que le produit propre, le monopole doit distordre le prix du produit propre relativement au niveau d'information complète.

On distingue deux formes de régulation lorsque l'équilibre sépare les deux types : (i) la régulation faible qui préserve l'avantage en coûts du monopole sale; (ii) la régulation forte qui donne l'avantage en coûts au monopole propre.

Le niveau de la taxe optimale doit être inférieur au niveau imposé en cas de monopole polluant avec information complète. La taxe comprend trois éléments correspondant aux externalités présentes sur le marché. En partant d'un niveau Pigouvien équivalent au dommage marginal, la taxe est ajustée selon le comportement du monopole qui restreint la production afin d'obtenir une rente non-compétitive. De plus, ce niveau est réduit encore pour prendre en compte l'impact de l'asymétrie d'information.

Puisque la taxe s'infiltré dans le prix du produit propre, que ce soit un équilibre séparateur ou mélangeant, l'espérance des consommateurs d'une haute qualité environnementale augmente l'importance que le régulateur attribue au produit propre. Cela entraîne la baisse de sévérité de la taxe environnementale relativement à la situation d'information complète.

En outre, sous un équilibre séparateur, la taxe ne peut plus égaliser la valeur sociale espérée d'un produit à son coût social espéré. Pour une régulation faible, en moyenne le prix doit être supérieur au coût social, cette relation s'inverse dans le cas d'une régulation

forte. Car l'information incomplète oblige le monopole propre à distordre son prix, la réaction du prix au changement de la taxe dépend de la position relative du prix du produit propre par rapport au niveau qui maximise le profit.

L'analyse de bien-être donne les résultats suivants : la régulation environnementale réduit le profit du monopole polluant qu'il y ait ou non séparation des types. La régulation environnementale augmente le profit du monopole propre dans le cas d'une régulation forte et dans le cas d'un équilibre mélangeant. Or, le bien-être des consommateurs du produit propre est en général réduit suite à la régulation environnementale.

2.1 Introduction

The regulation of polluting emissions plays an important role in preserving the natural environment. Mechanisms of pollution control and incentive schemes reduce environmental damage by constraining polluting emissions. Understanding how environmental regulations affect producers' strategic choices of price and quantity is thus of primary importance. The goal of the present paper is to analyze in an economy with imperfectly competitive markets and incomplete information about producers' environmental quality, how environmental regulations affect price signaling decisions.

The problem is relevant in markets with information asymmetry between producers and consumers where information disclosure is either not feasible or problematic. There are many examples of such. For instance, a producer in transition to organic agriculture¹ is unable to disclose his environmental type. The Volkswagen emissions scandal shows that certification or compliance with environmental quality standards does not necessarily ensure perfect availability of information on actual pollution. Sometimes there are grounds to dismiss labeling. An excessive use of organic fertilizers creates a high concentration of nitrates which degrades the virtue of organic quality. Cross pollination between organic and GM crops, possible under the current EU regulation, may confound environmental quality (Tickell 2015). Some wine producers deliberately avoid organic certification as it entails heavy bureaucratic procedures, inflexible certification costs and a long term commitment; while price adjustments are much less rigid. Indeed, there is a notion in France of reasonable agriculture which implies a reasonable use of chemicals. It is common knowledge that wine growers also consume their own product and logically don't have an incentive to ingest pesticides. Finally, the epidemic of *flavescence dorée* in France in 2012 may well illustrate how environmental labeling can be compromised. The *flavescence dorée* is a highly contagious epidemic that attacks vines threatening them in rapid extinction. The only efficient treatment is synthetic and does not conform to

¹The transition takes french vegetable farmers 2 to 3 years (Chambre d'Agriculture Rhône-Alpes 2015, p. 7).

organic principles. However, given the severity of the threat, the authorities and the certification entity have decided to enforce treatment in the affected and neighboring regions. In order to avoid noncompliance, the organic label is nevertheless maintained. As a result, the majority of producers have given way to synthetic treatment while few have opposed such (Berdah 2012).

To overcome information issue, a high quality producer could use price as an instrument of communication with consumers, thus signaling their own type².

Alas, environmental regulation, being put in force to constrain the pollution, may have a twisted impact on social welfare. Indeed, price signaling is based on the cost difference between the types allowing the high type to distinguish himself. The greater the cost difference, the cheaper is the signal³. In this light, the environmental regulation which increases the effective production cost of the polluting type directly reduces the cost difference. Thus, the price signal grows more expensive because it requires the high type to distort the price more. Ultimately, it produces a loss in consumer surplus. However, one can argue that severe environmental regulation which inverts the order of cost efficiency between types could increase the welfare. When the high type is more cost efficient, then the price is distorted downwards and the signal increases consumer surplus.

The aim of the paper is to analyze the impact of environmental regulation on the social welfare, taking into account distortions of the economy.

Literature review.

In this subsection we provide a brief overview of previous studies on communicating quality and how they relate to our research.

In the context of the second-best optimal policy with monopoly and pollution externalities we compare our results to those derived by (Buchanan 1969) and (Barnett 1980). The former questions Pigouvian approach for the case where organization cost -

²High environmental quality, organic quality are used as synonyms.

³I assume that quality is costly.

in the tradition of Coase, bribery between polluter and victims- is prohibitively high. He demonstrates that equalizing the marginal social to marginal private cost can degrade welfare since Pigouvian tax unduly restricts output that is already below the socially optimal level because of imperfect competition. The latter formalizes the model of market power in hands of polluting monopolist. (Barnett 1980) derives the second-best solution showing that optimal tax may fall short of the marginal damage and that the Pigouvian level of taxation may not be desirable when price elasticity of demand is not elastic.

(Bagwell and Riordan 1991) analyze the impact of incomplete information on monopoly pricing strategies. In a two-type model with informed and uninformed consumers and a costly quality provision, they demonstrate that the high type can find it profitable to distort the price of the high quality product, raising it above the full information monopoly level, to thus reveal its true type to consumers. By such deviation the high type gains the demand of uninformed consumers, who correctly infer the true type, at the cost of losing some profit margin due to suboptimal pricing. Given that the low type is more cost efficient, signaling price distortion must be just high enough to make mimicry of the low type unprofitable.

In a discrete type monopoly model, (Mahenc 2007) analyses pricing strategies for a firm of a superior environmental quality. Consumers, unable to observe or verify firm's environmental performance, have green preferences and are willing to reward high quality with price premium. He demonstrates that although signaling quality is a valid strategy for the clean type, it has a significant opportunity cost which increases with consumers' optimistic expectations about the firm's environmental performance, lower market power of the conventional variety or a lower gap between marginal costs of two types. These factors decrease profitability of the signaling strategy. A high level of optimism increases willingness to pay of uninformed consumers thus increasing pooling profits and the opportunity cost of price signal. The lower market power of a dirty producer corresponds to a lower price margin of the conventional variety implying that price deviation from a full information level becomes less expensive in view of the low type. Equivalently, the

less the cost differential, the lower the dirty type's opportunity cost, as its per unit loss from price distortion decreases. We continue the logic of plausible equilibria selection to analyze the impact of environmental regulation.

We adopt the market model similar to that of (Daughety and Reinganum 2008) in which signaling high quality and costly disclosure are unified in the monopoly setting with a continuum of types. Quality is costly, unverifiable and requires extra willingness to pay. The authors show that in signaling equilibria, with no possibility of disclosure, profits are decreasing in quality due to the need to distort price. This makes a fixed cost disclosure profitable for highest quality types explaining the incentive for voluntary disclosure and high quality provision.

In terms of pollution control, we complement the approach of (Sengupta 2012). In a two-type asymmetric information monopoly with green consumers, a clean firm signals its environmental performance. Pollution control is enforced through a market of pollution permits. The regulatory instrument - t , the price of the pollution permit, is exogenously given. Hence, the firm adapts its pricing strategy to the regulation which affects the relative cost efficiency between types. The author defines 'strong' regulation as such that inverts the cost order making the clean type more efficient. Thus, strong regulation induces a downward price signal and provides an incentive to invest in clean technology. Strong regulation is viewed as a means of overcoming the distortion of the incomplete information. We endogenize the instrument, derive the second-best optimal tax and perform a welfare analysis of environmental regulation taking into account the social cost of signaling price distortion under the condition of plausible equilibria.

(Antelo and Loureiro 2009) analyze the effect of quantity signalling and asymmetric information on environmental taxation. In a two-period Cournot oligopoly model where the regulator acts as a von Stackelberg leader, they show that the optimal second-best tax must be set below the level of the polluting monopoly, i.e., below the Buchanan benchmark. They find two additional effects induced by information asymmetry. The first information effect, deprives the regulator of an ability to distinguish between types,

requiring him to expand environmental regulation on clean types. The second signaling effect, makes both types of producers distort output from the profit-maximizing level. The attain separation the clean type must suppress and the dirty type must expand their output. Therefore, pollution coming exclusively from dirty types will inevitable grow with asymmetric information. The environmental tax must target not only the trade-off between output and pollution but also signaling distortion. Overall they show that the gap between marginal damage and the second-best optimal tax increases with incomplete information. Qualitatively, this is in line with our finding of a less stringent regulation, relative to the Buchanan benchmark, that we obtain for environmental regulation in a monopoly market with price signaling.

The paper is organized as follows. Section 2.2 presents the model. Section 2.3 derives equilibrium prices under incomplete information. Section 2.4 introduces the optimal environmental regulation. The implications for social welfare are discussed in Section 2.5. Section 2.6 concludes.

2.2 The model

Quality. Assume that a monopoly produces a product of environmental quality e which is unobservable to consumers before and after purchase, as for credence goods. Environmental quality can be high, \bar{e} , or low, \underline{e} , and is supplied by the clean or dirty producer respectively. The environmental quality implies a certain mode of production. The high environmental quality leaves an insignificant footprint as it uses clean electricity, recyclable materials, organic fertilizers etc. In contrast, the conventional type uses cheaper and dirtier electricity, creates waste and applies chemical fertilizers Hence e describes the production technology or abatement intensity. We make a standard assumption that the

environmental damage, d , is proportional to emissions⁴. The damage function is thus:

$$d(q, e) = \delta(\bar{e} - e)q \quad (2.1)$$

δ denotes the intensity of environmental damage per unit of output. It is a scientific estimate of the harm caused to the natural environment, to health and living quality, to air or water quality etc. q denotes the quantity of purchased units. e captures the actual environmental quality. The higher it is, the less damage is done per unit of output. We assume that the highest environmental quality is clean and free from pollution, while the conventional quality is dirty and its production ejects harmful emissions. The distribution of environmental quality is thus:

$$e = \{\underline{e}; \bar{e}\} \quad (2.2)$$

with $\underline{e} < \bar{e}$.

The following assumption states that the conventional variety is socially desirable and that consumers underestimate the damage to the environment caused by the dirty variety.

$$\gamma < \delta < \alpha - \gamma \quad (\text{A.3})$$

When disutility from pollution is less than the effective damage, then green consumers internalize environmental damage only partially⁵.

Consumers. Any type of product provides positive utility to consumers but the one with a higher environmental quality generates a higher utility. Consumers have green preferences (for the same price they favor the clean variety) as they experience disutility γ from insufficient (with respect to their individual ideal level of) environmental quality. The benefits derived from environmental quality are public and private simultaneously.

⁴See, for example, (Kurtyka and Mahenc 2011).

⁵This assumption is necessary to ensure that there is a pollution externality. If consumers were to have a correct estimate of environmental damage, i.e. $\gamma = \delta$, they would have internalized entirely pollution externality by their purchasing decisions. The demonstration is relegated to the appendix, see (2.7.2).

On the one hand, pleasure procured from a clean environment is non-rival and non-excludable. On the other hand, consumers get a direct and personal health benefit from the lack of or low content of nitrates, sulfites and pesticides. Consumers value these semi-public components of environmental quality and are eager to pay a premium for them.

The consumer's utility function is quasi-linear in all other goods⁶:

$$U(p, q, \hat{e}) = (\alpha - \gamma(\bar{e} - \hat{e}))q - \frac{1}{2}q^2 + I - pq \quad (2.3)$$

where α denotes gross willingness to pay for one unit of product, γ measures the disutility from lacking environmental quality, $\gamma > 0$, \hat{e} stands for perceived environmental quality determined as part of perfect Bayesian equilibrium where the firm's strategy is its price, I is income and p is price. Consumers may purchase multiple units of good, however sampling doesn't improve chances of future consumption satisfaction as with restaurant visits, medical consultations etc.

The consumers' demand for the good of perceived quality \hat{e} is given by:

$$q(p, \hat{e}) = \alpha - \gamma(\bar{e} - \hat{e}) - p \quad (2.4)$$

A representative consumer buys multiple units of a product; sampling succeeds or fails independently but with the same probability. To check the robustness, one can construct a market with heterogeneous consumers of mass M with unit demand. The taste or the reservation price for environmental quality, r , is distributed on the interval $[0, R]$. A consumer with a reservation price r buys one unit if $r - \gamma(\bar{e} - \hat{e}) > p$ and zero otherwise. The aggregate demand for the good is thus $q(p, \hat{e}) = \frac{M}{R}(R - \gamma(\bar{e} - \hat{e}) - p)$ which has the same form as the demand derived for the representative consumer.

Denote η price elasticity of demand: $\eta(p, \hat{e}) \equiv -\frac{\partial D}{\partial p} \frac{p}{D} = \frac{p}{\alpha - \gamma(\bar{e} - \hat{e}) - p}$. It is decreasing in perceived environmental quality, as $-\frac{\gamma p}{(\alpha - \gamma(\bar{e} - \hat{e}) - p)^2} < 0$. Higher expectations of envi-

⁶We adopted the structure of utility function from (Daughety and Reinganum 2008).

ronmental quality for a given price make consumers more captive from the monopolist's point of view.

To exclude trivial solutions, the following parameter restriction is necessary:

$$\alpha - \gamma > c(\bar{e}) \tag{A.1}$$

Assumption (A.1) implies that demand for each type is positive when the product is sold at marginal cost and with certainty perceived as dirty. (A.1) guarantees that even in the worst case a firm generates a positive profit⁷.

The firm. There is a single firm of type e . Its realization is determined by nature⁸. The firm produces the good at an effective marginal production cost $c(e)$ ⁹. As a baseline setting we assume that:

$$c'_e > 0 \tag{A.2}$$

where the subscript indicates the variable with respect to which the derivative is taken. The baseline assumption, (A.2), implies that the provision of environmental quality is costly. It is a conventional assumption, see for instance (Kurtyka and Mahenc 2011). Indeed, in agriculture engaging more manpower can substitute an extensive use of synthetic chemicals. Manual weeding that preserves soil quality has a much greater cost than the application of herbicides.

The firm may face a fixed cost of investment in high quality $F(e)$ with $F(\underline{e}) = 0$. However, the purpose of the investment is unobservable to consumers and therefore they are not able to infer quality level by observing $F(e)$ ¹⁰. An initial payment for the installation of clean-up filters or other abatement materials may illustrate this case.

⁷Note that Assumption A.1 implies $\gamma > c_e$: the cost increment from enhanced environmental quality is lower than the disutility from insufficient environmental quality. This ensures that the environmental quality provision is socially efficient.

⁸We abstract from producer's technology choice.

⁹ $c(e)$ accounts for all per unit expences the firm incurs during production, that is an after-tax - when relevant - per unit cost to the producer for a given environmental quality.

¹⁰In our model we adopt a similar cost structure as in (Andr e, Gonz alez, and Porteiro 2009).

The gross profit for the firm depends on its true price-cost margin and on the perceived environmental quality which affects the demand for the product. Hence, the generalized form of profit is:

$$\pi(p, e, \hat{e}) = (p - c(e))(\alpha - \gamma(\bar{e} - \hat{e}) - p) - F(e) \quad (2.5)$$

The profit function is strictly concave in p , it attains its maximum at $p^*(e) = \frac{\alpha - \gamma(\bar{e} - e(\mu_0)) + c(e)}{2}$. Henceforth, the ‘star’ superscript indicates a quantity obtained by monopoly maximization calculus.

The maximized profit is $\frac{(\alpha - \gamma(\bar{e} - e(\mu_0)) - c(e))^2}{4} - F(e)$. Lemma (7) summarizes the full information benchmark.

Lemma 7 *Under full information about environmental quality the producer charges the price*

$$p^*(e) = \frac{\alpha - \gamma(\bar{e} - e) + c(e)}{2} \quad (2.6)$$

that satisfies $\frac{p^*(e) - c(e)}{p^*(e)} = \frac{1}{\eta(p, e)}$ provided that $\eta(p^*(e)) > 1$ (for an interior solution).

Note also that the monopolist will optimally set the price in the price-elastic interval. Indeed, the monopolist chooses a price to solve the following maximization problem: $\max_p (p - c(e)) D(p, \mu)$. The FOC requires that $D(p, \mu) + (p - c(e)) \frac{\partial D}{\partial p} = 0$, which is, after rearranging, $1 - \eta = \frac{\partial D}{\partial p} \frac{c(e)}{D}$. Since the right hand side is clearly negative, it must hold that $\eta > 1$.

This is a standard result of monopoly pricing in which the price mark-up is equal to the inverse price elasticity of demand. It can be verified that $\eta(p^*(e))$ is increasing in e when evaluated at a profit-maximizing price. This implies that higher environmental quality has higher price elasticity compared to conventional quality¹¹.

¹¹Price elasticity increases with price ($\frac{\partial \eta}{\partial p} > 0$) and under complete information, the price increases with environmental quality ($\frac{\partial p^*}{\partial e} > 0$). Hence, the direct and indirect effects move in the same direction. This implies that price elasticity is increasing with environmental quality, that is, for the monopolist consumers become less captive.

The regulator. A benevolent regulator is aware of the environmental damage from the production of a conventional variety. He acts as a von Stackelberg leader wherein he chooses an optimal instrument that maximizes the standard utilitarian welfare.

The game. The sequence of the game is as follows: at stage 1 the regulator commits to an environmental policy. At stage 2 nature draws the firm's type, the firm learns its realization and sets the price. At stage 3 consumers purchase.

2.3 Asymmetric information

In this section we state the separating conditions and derive the equilibria under information asymmetry.

When consumers have an incomplete knowledge of the producer's environmental type, the firm's strategy is to choose a price that allows consumers to correctly identify its type/ environmental quality. Denote μ_0 to indicate consumers' prior belief of *high* environmental quality. It embraces all the information about environmental quality publicly available to consumers. Then, the perceived quality, \hat{e} , is the expected probability that the product is clean, that is $\hat{e} \equiv e(\mu_0) = \mu_0 \bar{e} + (1 - \mu_0) \underline{e}$. Rearranging (2.4) we obtain the demand as a function of the perceived quality:

$$q(p, \mu_0) = \alpha - \gamma(\bar{e} - e(\mu_0)) - p \quad (2.7)$$

Note that (2.7) increases in μ_0 implying that optimistic expectations of environmental quality raises demand. Since every producer type prefers to be taken for the clean regardless of its true type, the firm of type \bar{e} can benefit from revealing its true type when it distinguishes itself from the dirty type thus reaping the green consumption. The producer's objective is to maximize profit with respect to p given consumers beliefs about environmental quality.

The firm's strategy must form perfect Bayesian equilibrium where consumers infer environmental quality by observing the price. Let $\mu(\rho) : \mathbb{R}^+ \rightarrow [0, 1]$ denote a posterior

belief function that relates the firm's price to consumers' perception of environmental quality. Let $\rho(\bar{e})$ and $\rho(\underline{e})$ be the equilibrium prices for clean and dirty producers respectively. Thus, when a firm charges price $\rho(e)$, then it is inferred to have quality $\mu(\rho)$. Then, $(\rho(\bar{e}), \rho(\underline{e}), \mu(p))$ is the equilibrium strategy given the conditions:

1. For $e = \bar{e}, \underline{e}$ $\rho(e) = \max_p \pi(p, e, \mu)$.
2. If $\rho(\bar{e}) \neq \rho(\underline{e})$, then $\mu(\rho(\underline{e})) = 0$ and $\mu(\rho(\bar{e})) = 1$. If $\rho(\bar{e}) = \rho(\underline{e})$, then $\mu(\rho(e)) = \mu_0$.

The first condition states that for each type the price strategy must be profit-maximizing given consumers' beliefs. The second condition imposes the Bayes rule for belief updating. When the price is informative, consumers correctly identify the producers' type. When the price is uninformative, prior and posterior beliefs equal; and beliefs updating has no effect.

2.3.1 Separating equilibrium.

A producer of true environmental quality e who charges price p and who is perceived as type $\mu(e)$ ¹², obtains a profit of:

$$\pi(p, e, \mu(e)) = (p - c(e))(\alpha - \gamma(\bar{e} - \mu(e)) - p) - F(e) \quad (2.8)$$

We use the necessary and sufficient conditions derived in (Mailath 1987) to define the separating equilibrium:

1. $\frac{\partial \pi}{\partial \mu} \equiv \pi'_\mu = (p - c(e))\gamma > 0$ (belief monotonicity)
2. $\frac{\partial^2 \pi}{\partial e \partial p} \equiv \pi''_{ep} = \gamma\mu_e + c_e$ is strictly monotone in e (type monotonicity)
3. $S(p, e, \mu) \equiv \frac{dp}{d\mu} = -\frac{\pi'_\mu(p, e, \mu)}{\pi'_p(p, e, \mu)}$ is strictly monotone in e (single crossing)

¹²Since the posterior belief at equilibrium is the function of e , i.e., the true environmental quality, we can replace $\mu(\rho)$ with $\mu(e)$.

The explicit form of the marginal rate of substitution between the price and perceived environmental quality is:

$$S(p, e, \mu(e)) = -\frac{\gamma(p - c(e))}{\alpha - \gamma(\bar{e} - \mu(e)) - 2p + c(e)} \quad (2.9)$$

with:

$$S_e = \frac{\gamma}{\pi_p^2} [c_e(\alpha - \gamma(1 - \mu) - p) + (p - c(e))\gamma\mu_e] \quad (2.10)$$

$$= \frac{\gamma}{\pi_p^2} [c_e q(p, \mu(e)) + (p - c(e))\gamma\mu_e] \quad (2.11)$$

It is straight forward that $S_e > 0$ because γ and c_e are positive by assumption, demand and the price margin are positive numbers. Finally, when $c_e > 0$, consumers infer that high environmental quality is communicated by an upward price distortion, hence $\mu_e > 0$.

Condition 1 states that the firm's profit is always increasing in perceived environmental quality. Thus, the worst inference consumers' may draw about a firm's type is that $\mu = 0$. In that case, the dirty type would yet obtain the full information profit; the clean type, in contrast, would be worse off because it loses the entire demand for the clean variety. Hence, the clean firm *always* has an incentive to reveal its type. Condition 2 shows that the profitability of changing the price increases in e when $c'_e > 0$. Condition 3, known as single crossing property, indicates that the marginal rate of substitution between price and perceived environmental quality is a strictly monotone function of e . Indeed, when the product becomes cleaner, the firm is willing to charge more to benefit from green consumers' demand. Note that generally, the sign of $S(\bullet)$ in condition 3 depends on the p location relative to p^* . For an upward price distortion $\pi_p < 0$ and $S(\bullet) > 0$, for a downward price signal the signs reverse.

Recall, however, that $c(e)$ denotes the effective marginal cost of production. It implies that in the case of considerable environmental damage, a severe taxation regime on polluting emissions is capable of reverting this relation. This would entail a turnover in terms of cost efficiency, i.e. $c'_e < 0$. Then, Condition 1 holds with no change. As for

Conditions 2 and 3, the signs of their expressions invert. Indeed, $\frac{d\mu(\rho(e))}{de} = \frac{\partial\mu}{\partial\rho} \frac{\partial\rho}{\partial e} < 0$, since $\frac{\partial\rho}{\partial e} \equiv \frac{\partial p}{\partial e} \Big|_{p=p^*} > 0$ and $\frac{\partial\mu}{\partial\rho} < 0$ when $c'_e < 0$. As stated earlier, the price increases with environmental quality. When the clean type is less costly than the dirty, a downward price distortion ensures separation because by that action the clean type with certainty gains the green demand and loses less profit than the dirty type if the latter attempts to replicate the clean type's price. Since environmental regulation is common knowledge and consumers can observe its stringency, and beliefs in equilibrium are consistent, i.e. $\mu(\rho) = e$ for $e = \{\underline{e}; \bar{e}\}$, consumers correctly infer the clean type by its action - downward price distortion. As the dirty type has a greater effective marginal cost, a downward price signal, to mimic the clean type, is unprofitable.

Lemma 8 *Under conditions 1-3, separating equilibrium prices are such that $\rho(\underline{e}) = p^*(\underline{e})$ and (i) $\rho(\bar{e}) \geq p^*(\bar{e})$ when $c'_e > 0$ and (ii) $\rho(\bar{e}) \leq p^*(\bar{e})$ when $c'_e < 0$.*

Lemma 8 summarizes equilibrium pricing strategies. The dirty type charges the full information price, while the clean type distorts its price thus communicating to consumers superior environmental quality. The difference in effective production marginal costs determines the direction of price distortion.

Separating prices. Separating prices reveal producers' types. The dirty firm sets the full information monopoly price: $p^*(\underline{e}) = \frac{\alpha - \gamma + c(\underline{e})}{2}$. According to its price strategy, $\rho(\underline{e}) = p^*(\underline{e})$, it obtains the full information monopoly profit $\pi(\rho(\underline{e}), \underline{e}, 0) = \frac{(\alpha - \gamma - c(\underline{e}))^2}{4}$. Yet, if the dirty type were to be taken for the clean through setting $p = \rho(\bar{e})$, it would have reached the green consumers gaining the 'imitation' profit $\pi(p, \underline{e}, 1) = (p - c(\underline{e}))(\alpha - p)$. If, however, the clean type were to set up an uninformative price, it in turn would be taken for the dirty type. This would lead to 'confusion' profit $\pi(p, \bar{e}, 0) = (p - c(\bar{e}))(\alpha - \gamma - p) - F(\bar{e})$ which achieves maximum $p = \frac{\alpha - \gamma + c(\bar{e})}{2}$ yielding $\frac{(\alpha - \gamma - c(\bar{e}))^2}{4} - F(\bar{e})$.

To sustain separation, the clean type must set price $\rho(\bar{e})$ that verifies:

•

$$\pi(\rho(\bar{e}), \bar{e}, 1) > \max_p \pi(p, \bar{e}, 0) \quad (IR_C)$$

•

$$\max_p \pi(p, \underline{e}, 0) \geq \pi(\rho(\bar{e}), \underline{e}, 1) \quad (IC_D)$$

Condition (IR_C) requires that the clean type's profit at separation is greater than any other profit it may achieve when it is not correctly identified. Condition (IC_D) doesn't allow the dirty type to obtain a higher profit by deception than by revealing its true type. Denote ϱ_{IR} and ϱ_{IC} the set of prices that verify conditions (IR_C) and (IC_D) respectively (see 2.7.1 for details).

Proposition 9 *There is a set of separating equilibrium prices such that $\rho(\underline{e}) = \frac{\alpha - \gamma + c(\underline{e})}{2}$ and $\rho(\bar{e}) \in \varrho_{IR} \cap \varrho_{IC}$.*

The set of prices that sustain separation (and verify 9) contains an infinite number of prices. The equilibrium refinement criterion of (Cho and Kreps 1987) requires that price distortion is minimal. This gives the unique signaling price for high environmental quality.

Corollary 10 *The unique price that signals high environmental quality is (i) the lower bound $\underline{p}^s \in \varrho_{IR} \cap \varrho_{IC}$ when $c'_e > 0$ and (ii) the upper bound $\bar{p}^s \in \varrho_{IR} \cap \varrho_{IC}$ when $c'_e < 0$. The explicit formula for signaling price is:*

$$p^s = \frac{1}{2} \left[\alpha + c(\underline{e}) \pm \sqrt{\gamma(2\alpha - \gamma - 2c(\underline{e}))} \right] \text{ for } c'_e \gtrless 0 \text{ respectively} \quad (2.12)$$

To reveal the true environmental quality, the clean type must deviate from the full information profit maximizing level. In equilibrium, this allows consumers to correctly infer firm's environmental performance. When the clean type has greater marginal production costs, the signaling price exceeds the full information benchmark. In the opposite

case when the clean type is more cost efficient, i.e. $c'_e < 0$, the price deviation falls below p^* .

It is valuable to examine how the change in the marginal production cost of the dirty type affect the signaling price:

$$\frac{\partial p^s}{\partial c(\underline{e})} = \frac{1}{2} \left[1 \mp \frac{\gamma}{\sqrt{\gamma(2\alpha - \gamma - 2c(\underline{e}))}} \right] \text{ for } c'_e \gtrless 0 \text{ respectively} \quad (2.13)$$

It is straightforward that the sign of (2.13) is positive.

Corollary 11 *The signaling price always increases in the marginal cost of the dirty type.*

Proof. See 2.7.1. ■

An increase in the marginal production cost of the dirty variety reduces its profit and makes the deception strategy of price deviation from the full information level more attractive. To effectively separate itself from the conventional type, the clean firm must increase signaling distortion accordingly to discourage the dirty type from mimicking.

The profit the clean type earns when it signals its type is:

$$\pi^s(p^s(c(\underline{e}); \bar{e}, 1, c(\bar{e})) = [p^s(c(\underline{e})) - c(\bar{e})] \times q[p^s(c(\underline{e})), \bar{e}] \quad (2.14)$$

Note that the signaling profit depends on both dirty and clean marginal production cost, $c(\bar{e})$ and $c(\underline{e})$. It is clear that π^s decreases in $c(\bar{e})$. It is instructive to see how an increase in $c(\underline{e})$ affects the signaling profit:

$$\begin{aligned} \frac{\partial \pi^s}{\partial c(\underline{e})} &= \frac{\partial p^s}{\partial c(\underline{e})} \left[q^s[\bullet] - (p^s - c(\bar{e})) \frac{\partial q^s}{\partial p^s} \right] \\ &= \frac{\partial p^s}{\partial c(\underline{e})} \pi_p^{s'} \end{aligned} \quad (2.15)$$

As it has been shown, the first term is always positive. The second term in (2.15) represents the change of profit in the price. As profit has a normal concave form, it attains maximum at p^* , hence $\forall p > p^* \pi'_p < 0$ and $\forall p < p^* \pi'_p > 0$. Than is, profit is

decreasing in price when the price is distorted upward and it is increasing when the price is distorted downward.

Corollary 12 *The variation of π^s in $c(\underline{e})$ has the same sign as π'_p :*

$$\begin{cases} \frac{\partial \pi^s}{\partial c(\underline{e})} < 0 & \text{if } p^s > p^* \\ \frac{\partial \pi^s}{\partial c(\underline{e})} > 0 & \text{if } p^s < p^* \end{cases} \quad (2.16)$$

Signaling profit varies in the opposite direction of the price signal.

The intuition of this result is as follows. When the marginal cost of the dirty type increases, the signaling price rise. With upward distortion it implies an increase in the gap between the signaling and the profit-maximizing prices. With downward distortion, an increase of the signaling price brings it closer to the profit-maximizing level.

2.3.2 Pooling equilibrium.

Despite the existence of separating equilibria, there also exist pooling equilibria, some of which possibly dominate the least-costly separating price p^s , if the clean type's profit under pooling exceeds that under separating.

When prices are uninformative, consumers are unable to distinguish between the types¹³. Yet, given the assumption A.1 each product variety gets a positive demand (even with lowest expectations, i.e., $\mu_0 = 0$). When pooling price p^p is an element in a set of undefeated pooling equilibria prices, then a firm of type e obtains a pooling profit $\pi(p^p, e, \mu_0)$. As the pooling price is arbitrary, we assume that it is set by a producers' organization where interests of clean and dirty types are represented by their respective probability of occurrence. Since each e -type producer would prefer to set its profit-maximizing monopoly price $p^{p*}(e) = \frac{1}{2}(\alpha - \gamma(\bar{e} - \mu_0) + c(e))$, the interval of undefeated

¹³A full scale analysis of pooling equilibrium is beyond the scope of this paper. Therefore the pooling equilibrium serves solely to give an intuition of our argument.

pooling prices can be represented by the following:

$$p^p \in [p^{p*}(\underline{e}); p^{p*}(\bar{e})] \quad (2.17)$$

\mathbf{p}^{up} denotes the set of undefeated pooling prices in (2.17). It is clear that $p^{p*}(e) < p^{p*} < p^{p*}(\bar{e}) \quad \forall \mu_0 \in (0; 1)$.

The explicit form of pooling price chosen by the producers' organization is thus:

$$\begin{aligned} p^{p*} &= \mu_0 p^{p*}(\bar{e}) + (1 - \mu_0) p^{p*}(\underline{e}) \\ &= \frac{1}{2} [\alpha - \gamma(\bar{e} - \mu_0) + \mu_0 c(\bar{e}) + (1 - \mu_0) c(\underline{e})] \end{aligned} \quad (2.18)$$

which yields a pooling profit of:

$$\begin{aligned} \pi^p(p^{p*}, e, \mu_0) &= \frac{1}{2} [\alpha - \gamma(\bar{e} - \mu_0) + \mu_0 c(\bar{e}) + (1 - \mu_0) c(\underline{e}) - 2c(e)] \\ &\quad q(p^{p*}) - F(e) \end{aligned} \quad (2.19)$$

Now, consumers are not 'selective': each variety faces the same demand level for a given price. Obviously, with prior beliefs about environmental quality $\forall \mu \in (0, 1)$, the dirty type pooling profit is higher than with complete information. The exact opposite is true for the clean type.

For our purpose, it is of interest to see how a change in the effective marginal cost affects the pooling profit for each variety:

$$\frac{\partial \pi^{p*}(e)}{\partial c(e)} = \frac{\partial p^{p*}}{\partial c(e)} q(\bullet) + p^{p*} \frac{\partial q}{\partial p^{p*}} \frac{\partial p^{p*}}{\partial c(e)} \quad (2.20)$$

It is obvious that $\frac{\partial p^{p*}}{\partial c(e)} > 0$ for either type. Rearranging (2.20) we obtain: $\frac{\partial p^{p*}}{\partial c(e)} \left[q(\bullet) + p^{p*} \frac{\partial q}{\partial p^{p*}} \right] = \frac{\partial p^{p*}}{\partial c(e)} \pi_p^{p*'}(e)$. Hence, the sign of expression (2.20) depends on the location of the chosen pooling price with respect to that which maximizes each type's profit. Since for the dirty variety $p^{p*} > p^{p*}(\underline{e})$, the increase in its own marginal cost

reduces the pooling profit, and vice versa for the clean variety.

Note further that $\frac{\partial \pi^{p^*}(\bar{e})}{\partial c(\underline{e})} > 0$, i.e., an increase in the dirty product's marginal cost increases the clean type's pooling profit. An increase in $c(\underline{e})$ reduces the set \mathbf{p}^{up} , allowing the chosen pooling price come closer to the clean variety's profit-maximizing level.

Equilibrium selection.

The *intuitive* criterion (Cho and Kreps 1987) eliminates all the pooling equilibria and singles out the separating price p^s . Among all the equilibria (pooling and separating), one can rank the equilibria according to the Pareto dominance criterion. This is the spirit of the *undefeated equilibria* concept developed by (Mailath, Okuno-Fujiwara, and Postlewaite 1993). This criterion selects p^s over pooling equilibria when μ_0 is sufficiently low. For high enough values of μ_0 , some pooling equilibria, characterized by p^p , defeat p^s (Mahenc 2007).

According to the undefeated equilibria criterion, at Stage 2, the producer having learned its environmental type e , selects the price strategy that generates the highest profit. Given a parameter vector (α, γ, μ, F) , the pricing strategy is:

$$p(e) = \begin{cases} p^{p^*} & \text{when } \pi^p(p^{p^*}, e, \mu_0) > \pi^s(\rho, e, \mu(\rho)) \quad \text{for } e \in \{\underline{e}; \bar{e}\} \\ \rho(e) & \text{when } \pi^p(p^{p^*}, e, \mu_0) \leq \pi^s(\rho, e, \mu(\rho)) \quad \text{for } e \in \{\underline{e}; \bar{e}\} \end{cases} \quad (2.21)$$

When the pooling equilibrium pricing strategy Pareto dominates separating, then pooling is more profitable than separating for each type. The plausible choice of the producer of type e is to take a pooling price from the set \mathbf{p}^{up} . Hence, following the logic of the undefeated criterion, the firm prefers concealing information. In the opposite case, when separating is less costly than pooling, the clean type sets the signaling price and the dirty type sets the profit-maximizing full information price.

Figure (2-1)¹⁴ illustrates precisely this process. On the upper panel, continuous curves

¹⁴The graph represents a general case for arbitrary c for expositional reasons. However, according to Assumption (A.1), only the part for which $c < \gamma$ is relevant to ensure socially efficient supply of

represent both types' profit functions when correctly identified by consumers. Dashed lines depict profits when each type is taken for its counterpart. The thick horizontal lines correspond to incentive constraints for dirty and clean producers, the overlapping of which gives a set of signaling prices that allows effective separation between the types. As mentioned earlier, the pair of prices $(p^s, p^*(\underline{e}))$ survives selection by the intuitive criterion. This specifies the unique separating equilibrium.

On the lower panel, dot-dashed curves depict pooling profits for each variety as an expected quality characterized by prior beliefs μ_0 .

Obviously, for an infinite number of sufficiently large μ_0 , the set \mathbf{p}^{up} will always defeat separating if applying Mailath's criterion. This is precisely the effect identified in (Mahenc 2007) of overly optimistic consumers' expectations. For our purpose, notice that the change in c (which measures the difference in effective marginal production costs, i.e., $c \equiv c(\bar{e}) - c(\underline{e})$) will have a similar effect on the equilibria selection.

Converting the same concept into the (c, α, π) space makes it possible to map each (c, α) pair to an equilibrium selected by the undefeated criterion¹⁵. In Figure 2-2, plausible equilibria in terms of π are projected on the (c, α) plane. Hence, on the horizontal axes c denotes the difference in the effective marginal production cost between the clean and dirty types. On the vertical axes α denotes the gross product valuation. The colored upper left triangle corresponds to the region where Assumption A.1 is verified, i.e., the manufacturing of either variety is desirable. Here, μ_0 is fixed at an arbitrary level and c is set as the variable. Intuitively, for a given α , in the limit, for $c \rightarrow 0$ (with no difference in marginal costs), the set of undefeated pooling prices is reduced to a unique point which yields the maximal monopoly profit for expected environmental quality. For $c \rightarrow \infty$, the full information monopoly price allows for separation with no price distortion because the dirty type can no longer profitably imitate the clean variety. Indeed, for sufficiently large c , the gain from additional green consumers and the higher price margin doesn't

environmental quality.

¹⁵See Appendix 2.7.3 for its derivation.

cover the loss of conventional consumers due to this price increase.

In Figure (2-1) from left to right, with an increasing c , first pooling equilibrium defeats the separating price, then the relation inverts. Note that all along the c axis, the profit of the clean type is steadily decreasing.

2.4 Environmental regulation

The misallocation of resources comes from three sources in this economy; from external damage, from imperfect competition, and from incomplete information. Ideally, three corrective instruments would be needed to restore efficiency: one to increase production of the final good, a tax to control external diseconomies and an information revelation device. It is assumed, however, that product market distortion cannot be directly corrected. The unobservability is inherent in environmental quality and can only call for the search for efficient revealing mechanisms¹⁶. So the pollution tax is the optimal second best trade-off among the diseconomies.

Assuming that the society is indifferent to redistribution effects (all funds collected through the environmental regulation are transferred back to consumers) and abstracting from the shadow price of public funds, the sum of consumers' and producer's surpluses, and the taxes levies net of environmental damage can be used as welfare measures¹⁷. For

¹⁶In our model, incomplete information of a product's environmental quality concerns exclusively the product market, as the regulator can observe the firm's type. An alternative model of incomplete information between the regulator and the producer would require a menu of contracts capable of revealing producers' true types, in the spirit of (Freixas, Guesnerie, and Tirole 1985). Although in practice, lump-sum transfers are met with strong political resistance, it would be of interest to examine the efficiency of those contract menus in terms of their capacity to reveal information. However, it is beyond the scope of this paper.

¹⁷It is the exact measure of welfare for in our model preferences are quasi-linear coving a large range of consumer goods plagued by incomplete information (wines, for example).

a given realization of environmental quality e , social welfare is thus expressed:

$$\begin{aligned} W(e) &= \int_0^{q(e)} P(x) dx - c(e)q(e) - \delta(\bar{e} - e)q(e) - F(e) \\ &= \left(\alpha - \gamma(\bar{e} - e) - \frac{1}{2}q(e) - c(e) - \delta(\bar{e} - e) \right) q(e) - F(e) \end{aligned} \quad (2.22)$$

It measures the social value of traded goods, net production costs and aggregate damage to the environment.

In the following subsection, we separately examine the properties of the optimal second-best environmental tax and its impact on producer's pricing decisions when equilibria are selected according to intuitive and undefeated criteria.

2.4.1 Environmental taxation

The regulator has an objective to maximize the aggregate social welfare by imposing a tax on the polluting emissions. At the time when the regulation is set, a realization of the production type has not yet taken place, so the regulator commits to a policy in anticipation of a probability μ_0 , that the producer is of the clean type. Hence, the regulator's objective function is $W(t)$:

$$\max_t \mu_0 W(\bar{e}, t) + (1 - \mu_0) W(\underline{e}, t) \quad (2.23)$$

The probabilistic welfare is similar to that of (Freixas, Guesnerie, and Tirole 1985), in our context, alternatively to consumers' prior optimism about the firm's environmental performance, μ_0 can represent the percentage of clean markets in the economy as a whole.

Optimal second-best tax with equilibrium selection by intuitive criterion.

The unique equilibrium, which survives the intuitive criterion, is separating with the price pair $(p^s, p^*(\underline{e}))$, and is such that the clean type sets the least distortionary signaling price while the dirty type sets a full information monopoly price. Then, using (3.30) we obtain

the explicit form of the regulator's objective function:

$$\begin{aligned}
W(t) = & \mu_0 \left[\left(\alpha - \frac{1}{2} q(p^s(\bar{e}, t)) - c \right) q(p^s(\bar{e}, t)) - F(\bar{e}) \right] + \\
& (1 - \mu_0) \left[\alpha - \gamma(\bar{e} - \underline{e}) - \frac{1}{2} q(p(\underline{e}, t)) - c(\underline{e}) - \delta(\bar{e} - \underline{e}) \right] q(p(\underline{e}, t))
\end{aligned} \tag{2.24}$$

With no loss of generality, set $\bar{e} - \underline{e} \equiv 1$. The first order condition (FOC) of (2.24) requires that:

$$\mu_0 \frac{\partial q}{\partial p^s} \frac{\partial p^s(\bar{e})}{\partial t} (p^s(\bar{e}, t) - c(\bar{e})) = (1 - \mu_0) \frac{\partial q}{\partial p^*} \frac{\partial p^*(\underline{e})}{\partial t} (\delta - [p^*(\underline{e}, t) - c(\underline{e})]) \tag{2.25}$$

To ensure that welfare attains in t its maximum, the second order condition (SOC) must be negative, the demonstration of which is relegated to Appendix 2.7.3.

Condition 2.25 states that the weighed sum of the expected value of the ‘social’ price margins of both types must equal zero. The term ‘social’ emphasizes the total production cost incurred by society, including environmental damage. As the clean variety is pollution free by assumption, its social price margin is the same as its (standard) price margin which measures the difference between the signaling price and the marginal production cost. For the dirty type, in contrast, the social price margin, accounting for its marginal damage, is the gap between the full information monopoly price and the total social cost. These price margins are weighed by the probability of the occurrence of the corresponding environmental type, and by the demand sensitivity to the price change induced by the tax. The social price margin of the clean variety is always positive because the signaling strategy ensure strictly positive profits. Consequently, the social price margin of the dirty variety must be strictly negative at the optimum. This implies that the dirty type's unregulated monopoly price is below its social optimum, and, under complete information, the optimal second-best tax on the dirty variety would be positive. Hence, the optimality of environmental regulation is conditional on sufficiently high damage from production

of the dirty variety.

Definition 13 Denote $t^{wk} : c(\underline{e}, t) < c(\bar{e})$ weak environmental tax associated with weak environmental regulation; and $t^{st} : c(\underline{e}, t) > c(\bar{e})$ strong environmental tax associated with strong environmental regulation.

Recall that since the level of environmental tax, t , depends on the intensity of polluting emissions, which are in turn a function of e , we count the tax a part of the effective marginal production cost.

All tax rates that preserve the cost advantage of the dirty variety relative to the clean variety correspond to *weak* environmental regulation. All tax rates that turn over the cost efficiency between the types represent *strong* regulation.

Recall that $\frac{\partial p^s}{\partial t} = \frac{1}{2} \left(1 \mp \frac{\gamma}{\sqrt{\gamma(2\alpha - \gamma - 2t)}} \right) > 0$ for upward and downward price distortion respectively. Then simplifying (2.25), the FOC reduces to:

$$\mu_0 \frac{\partial p^s}{\partial t} (p^s(\bar{e}, t) - c(\bar{e})) = (1 - \mu_0) (\delta + c(\underline{e}) - p^*(\underline{e}, t)) \quad (2.26)$$

Since with upward price distortion $0 < \frac{\partial p^s}{\partial t} < 1$ and with downward price distortion $1 < \frac{\partial p^s}{\partial t}$, it allows the following.

Proposition 14 *With weak regulation the expected price is above the expected social cost of the two varieties, with strong regulation the expected price is below the expected social cost:*

$$\begin{cases} \mu_0 p^s(\bar{e}, t) + (1 - \mu_0) p^*(\underline{e}, t) > \mu_0 c(\bar{e}) + (1 - \mu_0) (\delta + c(\underline{e})) & \text{if } c_e > 0 \\ \mu_0 p^s(\bar{e}, t) + (1 - \mu_0) p^*(\underline{e}, t) < \mu_0 c(\bar{e}) + (1 - \mu_0) (\delta + c(\underline{e})) & \text{if } c_e < 0 \end{cases} \quad (2.27)$$

The condition specified in Proposition 14 states that under weak regulation consumers pay for the product on the average more that it costs to society, while under strong regulation they, in expectation, underpay. This result is driven by the inertia of the clean type's signaling price. The response of the clean producer to an increase in

$c(\underline{e}, t)$, induced by t , under weak regulation pushes the clean type to ‘reluctantly’ distort the signaling price further away from the profit-maximizing level. Under strong regulation however, an increase in tax directly increases the clean type’s profit, so the clean type is willing to further distort its signaling price toward its optimal monopolistic price. Therefore, when it come to comparison with the optimal solution under full information, then standard Buchanan result requires the second-best optimal tax to equalize the price of the polluting monopoly to its social cost: $p^{Buch}(t, e) = \delta(\bar{e} - e) + c(e)$. This achieves optimal resource allocation and the (first-best) optimal output level (apart from redistributive issues since the monopoly exerts market power). Under incomplete information, optimal resource allocation is no longer attainable.

Claim 15 *Strong environmental regulation can pertain and be optimal if and only if the probability of the clean variety is low, i.e., for $\mu_0 < \frac{1}{2}$.*

Proof. See 2.7.3. ■

Claim (15) is intuitive because the expected environmental damage must exceed the expected value of clean variety.

Since the pollution tax is set proportionally to emissions, it enters linearly into the effective marginal cost function, i.e., $c(e, t) \equiv c(e) + t(\bar{e} - e)$, the full information monopoly price of the dirty firm rises at $\frac{a-\gamma+c(\underline{e})+t(\bar{e}-\underline{e})}{2}$. The private FOC of profit maximization states $\frac{\partial \pi}{\partial q} = \frac{\partial p(q)}{\partial q}q + p(q, e) - c(e) - t(\bar{e} - e)$. This makes it possible to present $p(q, e) - c(e) = t(\bar{e} - e) - \frac{\partial p(q)}{\partial q}q$ or in terms of price elasticity $\frac{p(q,e)-c(e)}{p(q,e)} = \frac{t(\bar{e}-e)}{p(q,e)} - \frac{p(q,e)}{\eta(p,e)}$. Substituting for the price margin of the conventional environmental quality gives the general form of the optimal second-best environmental tax:

$$t^* = \delta - \frac{1}{\bar{e} - \underline{e}} \left(\frac{p^*(\underline{e}, t)}{\eta(p^*(\underline{e}, t), \underline{e})} + \frac{\mu_0}{1 - \mu_0} \frac{q'_t(p^s)}{q'_t(p^*)} [p^s(\bar{e}, t) - c(\bar{e})] \right) \quad (2.28)$$

For expositional reasons replace $\bar{e} - \underline{e} = 1$ and $q_t(p^s) = \frac{\partial q}{\partial p} p'_t$, then the tax becomes:

$$t^* = \delta - \frac{p^*(\underline{e}, t)}{\eta(p^*, \underline{e})} - \frac{\mu_0}{1 - \mu_0} \frac{p'_t}{p'_t} [p^s(\bar{e}, t) - c(\bar{e})] \quad (2.29)$$

Or explicitly:

$$t^* = \delta - (\alpha - \gamma - c(\underline{e}) - \delta) - \frac{\mu_0}{1 - \mu_0} \frac{p_t^{s'}}{p_t^{*s'}} [p^s(\underline{e}, t) - c(\bar{e})] \quad (2.30)$$

Clearly, expression (2.29) is not the explicit solution for t because t is on both sides of the equation. It allows nevertheless for economic interpretation. The optimal second-best environmental tax is composed of three elements that account for three distortions in the market: marginal environmental damage, δ , monopoly pricing and incomplete information. Each distortion, having its proper impact on the welfare, finds its reflection in the formula of the optimal environmental tax.

The Pigouvian taxation level serves the ultimate benchmark of regulation, fully internalizing pollution damage. However, in the presence of market power as it has been shown by (Buchanan 1969) and (Barnett 1980), the severity of environmental regulation must be set below the Pigouvian level. The monopolist restraining output to obtain monopoly rent thus restrains polluting emissions as well. Let us adopt the term ‘Buchanan tax’ to designate the optimal second-best tax on the polluting monopoly. A finite price elasticity of demand, η , is crucial to support Buchanan tax level. Otherwise, market power vanishes and optimal tax regains Pigouvain level since the third term in (2.29) disappears as the price margin falls to zero.

The last element in (2.29) is in the center of our interest. This term measures the impact of incomplete information on the optimal second-best tax. This term contains three elements: the relative probability of occurrence of the clean type, the relative sensitivity of the price to a change in the tax and the signaling price margin of the clean variety. All three components are always positive implying that the externality of imperfect information further reduces the severity of environmental regulation. This happens because the signaling price is dependent on the marginal production cost of the dirty variety. The imposition of a tax increases the dirty type’s cost making deception more attractive. It forces the clean type to additionally adjust its signaling price to discourage imitation. Hence, green consumers carry the burden of environmental taxation

as they must pay a higher signaling price. The clean type's profit varies in the opposite direction of the signaling distortion. Hence, when the strong regulation is enforced, the clean type benefits because its signaling price moves closer to the full information profit-maximizing level. However, the producer's gain doesn't make up for the reduction in the surplus of consumers. The price increase induced by the emission tax generates a deadweight loss for the clean variety with no benefit of pollution control.

Following (Mahenc 2007), let us examine the impact of consumers' prior beliefs on the level of an optimal environmental tax.

Corollary 16 *Under separating equilibrium, consumers' greater expectations with respect to environmental quality alleviate the severity of regulation:*

$$\frac{\partial t^*}{\partial \mu_0} < 0 \tag{2.31}$$

Proof. See (2.7.4). ■

Corollary 16 gives the relation between tax stringency and the consumers' prior beliefs about environmental performance. As consumers grow more enthusiastic, the tax level must decrease. This result is in line with Claim 15. As consumers place greater expectations on high environmental quality, the relative importance of pollution control diminishes.

Let us examine the extreme values of consumers' expectations. When $\mu_0 \rightarrow 0$, the optimal second-best tax in (2.29) shrinks to the Buchanan tax on a polluting monopoly. When, on the contrary, $\mu_0 \rightarrow 1$, the FOC in (2.25) is reduced to: $\frac{\partial p^s}{\partial t} [p^s(\underline{e}, t) - c(\bar{e})]$. With no pollution externality, the tax aims at eliminating the positive price margin of the clean variety. Yet, given $\frac{\partial p^s}{\partial t} > 0$, any positive tax would only aggravate the existing distortion. Thus, intuitively, a pollution tax is unable to correct pricing distortions stemming from the signaling behavior of the non-polluting variety.

Optimal second-best tax with equilibrium selection by undefeated criterion.

As stated earlier, the Mailath's undefeated equilibrium criterion may select pooling equilibria over separating. This is the case for sufficiently high μ_0 (Mahenc 2007). We argue that a sufficiently low c , that is $\forall c < \hat{c} : \pi^p(p^{p^*}(\hat{c}), e, \mu_0) = \pi^s(\rho(\hat{c}), e, \mu(\rho(\hat{c})))$, may as well invoke similar results.

To see how environmental regulation may affect plausible equilibria selection by the undefeated criterion consider the situation depicted in Figure (2-3). On the upper panel, the before-tax separating equilibrium is Pareto dominant. Yet, tax implementation, reducing relative cost difference between the types, changes the equilibria ranking: the after-tax pooling equilibrium¹⁸ Pareto dominate separating, depicted on the lower panel. Thus, for all *marginal* separating equilibria where the clean type is only slightly better off revealing information than concealing it, environmental taxation will necessarily reverse the choice of pricing strategy.

Given distribution of types, production costs and consumers' disutility from pollution, the regulator can anticipate which equilibrium survives the selection by the undefeated criterion. For all undefeated pooling equilibria and all marginal separating equilibria, the regulator will maximize the probabilistic welfare (2.23) given uninformative pricing. Then, the regulator's objective function is:

$$\begin{aligned} \max_t \quad W(t) = & \mu_0 \left[\alpha - \gamma(\bar{e} - \mu_0) - \frac{1}{2}q(p^{p^*}(t, \mu_0)) - c(\bar{e}) \right] q(p^{p^*}(t, \mu_0)) \\ & + (1 - \mu_0) \left[\alpha - \gamma(\bar{e} - \mu_0) - \frac{1}{2}q(p^{p^*}(t, \mu_0)) - c(\underline{e}) - \delta \right] q(p^{p^*}(t, \mu_0)) \end{aligned} \quad (2.32)$$

Rearranging social welfare gives:

$$\begin{aligned} W(t) = & \left[\alpha - \gamma(\bar{e} - \mu_0) - \frac{1}{2}q(p^{p^*}(\bullet)) \right] q(\bullet) \\ & - [\mu_0 c(\bar{e}) + (1 - \mu_0)(c(\underline{e}) + \delta)] q(\bullet) \end{aligned} \quad (2.33)$$

¹⁸For technical reasons, we focus on pooling equilibria at $p^{p^*}(\bar{e})$ which produces qualitatively the same results.

the objective function, with the optimal second-best tax, must be to equalize the product's social value given the expected environmental quality with the expected social production cost of the clean and dirty varieties.

Under pooling equilibrium, the FOC requires that the optimal second-best environmental tax is set at:

$$t^{p*} = \delta - (\alpha - \gamma - c(\underline{e}) - \delta) - \frac{\mu_0}{1 - \mu_0} [\alpha - c(\bar{e})] \quad (2.34)$$

As in (2.29), under pooling equilibrium the optimal second-best environmental tax is composed of three elements responsible for the correction of corresponding diseconomies. First, it is the correction of pollution externality at the level of marginal environmental damage. Second, it is the correction of monopoly pricing given expectations of environmental quality, and lastly, the correction for incomplete information. Also in this tax version, the presence of information asymmetry requires the scaling down of tax stringency: $\forall \mu_0 > 0$ the optimal tax must be below the Buchanan level. However, now it is the net social value of the clean variety (and not the price margin) by which the tax is adjusted. The pooling price is the same for each variety but proportional to pollution tax. With greater social value of the clean variety, the regulator must take into account the restrictive effect of the tax on the pooling price.

Corollary 17 *Under pooling equilibrium, greater consumers' expectation with respect to environmental quality alleviate the severity of regulation:*

$$\frac{\partial t^{p*}}{\partial \mu_0} < 0 \quad (2.35)$$

Proof. Stems directly from: $\frac{\partial t^{p*}}{\partial \mu_0} = -\frac{\alpha - c(\bar{e})}{(1 - \mu_0)^2}$. ■

Under pooling equilibrium, an increase in μ_0 increases the value the clean variety receives in the eyes of the regulator. Therefore when setting an optimal tax, higher consumers' expectations make the regulator favor the clean variety, and because of the negative effect of the tax on social welfare that results from the trade of the clean variety,

the tax level must be reduced accordingly.

Special case: $c(\bar{e}) = c(\underline{e})$

By construction the clean firm differs from the dirty one in either its marginal production cost and/or in its fixed cost. Complementary to our previous discussion, in this subsection we examine the case where only technology investment is at the origin of high environmental performance (holding marginal production costs equal). With no loss of generality, set $c(\underline{e}) = 0$ and assume that the fixed cost is sufficiently small not to interfere with monopolist's incentive to produce output, i.e., $F(\bar{e}) \leq \frac{(\alpha-\gamma)^2}{4}$.

Before pollution control is enforced, Condition (2) for a separating equilibrium does not hold. When both types receive equal price margins, the clean type can no longer attract green demand and at the same time effectively discourage mimicry. Hence, in an unregulated market the only possible equilibria type is pooling.

It is obvious that implementation of environmental regulation would immediately satisfy Condition (2) enabling separating equilibria. Since after tax the dirty firm becomes less efficient with $c < 0$, the clean type is better off with downward price signal.

Proposition 18 *When $c(\bar{e}) = c(\underline{e})$, environmental taxation with $t > 0$ (i) induces a downward price signal and (ii) represents strong regulation.*

Proof. For (i) see the discussion following separating equilibrium conditions (3), (ii) by definition. ■

Thus, environmental regulation may have a major positive impact on the informational issue proposing an alternative to uninformative pricing. The intuitive criterion selects the unique separating equilibrium with a downward distortion of the clean variety's price: $\rho(\bar{e}) = \frac{1}{2} \left(\alpha + t - \sqrt{\gamma(2\alpha - \gamma - 2t)} \right)$ and $\rho(\underline{e}) = p^*(\underline{e})$; the undefeated criterion selects separating equilibria once t is large enough to Pareto dominate the pooling equilibria.

2.5 Welfare implications

In this section we evaluate the impact of environmental taxation on social welfare.

Separating equilibrium. When weak regulation is required, it partially internalizes the externality from the polluting production of the dirty product. The clean product also grows more expensive making consumers' and producer's surpluses shrink. It represents a mere deadweight loss because the reduction of output doesn't serve to control or limit pollution.

When strong regulation is required, the clean variety signals its quality by downward price distortion. Compared to upward signaling, consumers are better off as they benefit from the lower price of the clean variety. In terms of surplus, the clean producer is indifferent to upward and downward price distortion because in the former case a high price margin compensates for thinner demand and vice versa in the latter case. Compared to socially optimal resource allocation, strong regulation with downward price distortion performs relatively better than the weak because both price and output of the clean product are closer to the competitive level. It is clear however, that the optimality of such a severe environmental policy is conditional on relatively high environmental damage, low consumers' expectations, and a sufficiently high difference in marginal costs. Figure (2-4) illustrates a parameter map for which all the conditions are verified. As either constraint is relaxed, the strong tax ceases to be optimal because of its high social cost.

It is noteworthy that for both types of regulation, optimistic expectations about environmental quality lessen the severity of the environmental tax. With upward signaling, there is a deadweight loss from the reduced amounts of trade of the clean variety. With downward signaling, it is rather the exercise of market power by the clean type, which enables the signaling price to approach monopoly level.

Pooling equilibrium. When prices are uninformative, the pollution tax affects the pooling price. The optimal tax corresponds to the Buchanan level, softened by the

probability of occurrence of the clean variety. The optimal tax equalizes the product's expected social value to its expected social cost. For the dirty variety, the tax doesn't entirely corrects pollution externality. For the clean variety, the tax reduces the amount of trade. In addition, private information about environmental quality remains concealed.

Equilibrium selection by undefeated criterion. As it has been shown for equilibria selection according to Mailath's undefeated criterion, environmental taxation may affect a producer's pricing strategy. Thus, the marginal producer who is ex-ante better off with a separating price strategy, would ex-post 'migrate', subsequent to the imposition of weak environmental regulation, to a pooling price strategy. Similarly, to have a downward price signal induced by strong environmental regulation, environmental damage must be sufficiently close to the dirty variety's social value and the tax level should more than double the difference in marginal production costs, i.e., $t > 2c$. The first c is necessary to reverse the order of cost efficiency, the second - to induce a signaling strategy. Because even being more cost efficient, the clean type's pooling profit would Pareto dominate its separating profit, if it costs almost the same to produce a high or a low environmental quality. Thus, the tax may make the clean type prefer the pooling strategy over the separating strategy.

The 'equilibrium migration' induced by environmental regulation has a negative effect on welfare because consumers lose the ability to distinguish between environmental types when environmental regulation renders pooling equilibrium Pareto dominant.

Efficiency of environmental regulation. Given the complexity of consequences of environmental taxation on imperfectly competitive markets plagued by incomplete information about environmental quality, one may wonder if such a policy can in fact be efficient. The result of uninformative pricing is deemed suboptimal while the regulation under separating equilibrium is associated with high social costs. What might seem appealing in environmental policy - apart from the control over pollution externality - is that strong regulation has the ability to induce a downward price signal so beneficial

to consumers. However, it can be shown that a welfare neutral strong subsidy from consumers to the clean producer (such that would not only buy off clean type's marginal production cost but also make separating equilibrium Pareto dominant) would attain the same result but at a lower social cost, casting doubts on the desirability of strong environmental taxation.

2.6 Conclusion & discussion

In this paper we studied the impact of price signaling under asymmetric information on the optimal design of the second-best environmental tax.

The main contribution to existing literature is that we endogenize environmental regulation to emphasize its impact on social welfare. In the framework of imperfectly competitive industry with incomplete information about environmental quality, the firm may communicate this quality to consumers by distorting the product's price from its profit-maximizing level. This price strategy allows the firm to attract green consumers who can infer a firm's true type by observing price deviation.

We first examine equilibrium pricing for two quality types according to intuitive and undefeated equilibria selection criteria. Then we derive the optimal second-best environmental tax. We show that the tax rate must be scaled down below the level optimal for a polluting monopoly under complete information. This result is driven by two effects. First, positive consumers' expectations of clean production lower the stringency of the tax, because the clean type does not emit pollution. Second, the mechanics of price signaling make the clean variety more expensive for no environmentally grounded reason. This constitutes a social cost of regulation for which incomplete information is responsible. While an environmental tax affects optimal pricing of both clean and dirty varieties, for the dirty type, the tax serves to correct pollution externality, for the clean type it represents a mere undesirable by-product. The reduction of trade of the clean variety induced by environmental taxation represents a direct loss to society.

Our finding with respect to the optimal second-best tax level is consistent with the literature. Indeed, (Antelo and Loureiro 2009) come to a similar conclusion that informational deficiency on part of the regulator makes the regulation less severe compared to the level required for a polluting monopoly.

We demonstrate that first-best resource allocation, still attainable in the absence of information asymmetry, cannot be achieved under incomplete information. As price signaling has an unequal sensitivity to policy stringency, it must be on the average either unduly lax or unduly stern at the expense of the consumers' welfare.

Finally, we show that environmental policy may produce a perverted effect on market equilibrium. When considering the criterion of undefeated equilibria, the implementation of an environmental tax may remove the incentive for the clean producer to reveal its true type to uninformed consumers. Thus, subsequent to environmental taxation, pooling may turn Pareto dominant over separating equilibria.

The complex structure of environmental taxation, its high social cost and the possibility of undesirable equilibria migration, all call for great caution when contemplating the implementation of a market-based instrument to correct pollution externality when the market in question is characterized by multiple distortions.

2.7 Appendix

2.7.1 Derivation of signalling price

Case 19 1: *signalling high environmental quality without regulation*

The clean variety will signal the high environmental quality (HEQ) it must hold that the profit under the signaling strategy is greater the HEQ is not correctly identified. The

individual rationality (IR) for the clean variety, RI_{HEQ} , is thus:

$$\pi(p, \bar{e}, 1) \geq \max_p \pi(p, \bar{e}, 0) \quad (2.36)$$

$$(p - c)(\alpha - p) \geq \max_p \pi(p, \bar{e}, 0) \quad (2.37)$$

Note that in the worst case when consumers fail to identify HEQ, the highest profit the clean variety can obtain solves: $\max_p (p - c)(\alpha - \gamma - p)$. The optimal profit at the level of profit-maximizing price is thus $\frac{(\alpha - \gamma - c)^2}{4}$.

Rewriting the RI_{HEQ} we obtain the condition:

$$(p - c)(\alpha - p) \geq \frac{(\alpha - \gamma - c)^2}{4} \quad (2.38)$$

Similarly, for the dirty type, RI_{LEQ} is $p(\alpha - \gamma - p) \geq \frac{(\alpha - \gamma)^2}{4}$ which is an identity. Hence, 2.38 is the only bounding condition among the RI.

The incentive compatibility constraints ensures that the profit generated from truth-telling is higher than mimicking the other type. The IC_{HEQ} is for either type is thus:

$$\pi(p^*, \bar{e}, 1) \geq \pi(p, \bar{e}, 0) \quad (2.39)$$

$$\frac{(\alpha - c)^2}{4} \geq (p - c)(\alpha - \gamma - p) \quad (2.40)$$

This constraint is verified if the RI_{HEQ} holds.

Lastly, the compatibility constraint for the low environmental quality (LEQ) type, CI_{LEQ} , is:

$$\pi(p^*, \underline{e}, 0) \geq \pi(p, \underline{e}, 1) \quad (2.41)$$

$$\frac{(\alpha - \gamma)^2}{4} \geq p(\alpha - p) \quad (2.42)$$

Note that $p^* = \max_p p(\alpha - \gamma - p) = \frac{(\alpha - \gamma)^2}{4}$.

The signalling price of the HEQ must verify the system of bounding conditions RI_{HEQ}

and CI_{LEQ} :

$$\begin{cases} (p - c)(\alpha - p) \geq \frac{(\alpha - \gamma - c)^2}{4} \\ \frac{(\alpha - \gamma)^2}{4} \geq p(\alpha - p) \end{cases} \quad (2.43)$$

Note that the two conditions can be rewritten as a function:

$$f(p, c) = (p - c)(\alpha - p) - \frac{(\alpha - \gamma - c)^2}{4} \quad (2.44)$$

To find the separating equilibrium the system must hold

$$f(p, c) \geq 0 \geq f(p, 0) \quad (2.45)$$

The 2.43 represents two inequalities for polynomials, whose solution must be the overlap of intervals defined by the two conditions. The price solving the equation $f(p, c) = 0$ is

$$p(c)_{1,2} = \frac{1}{2} \left(\alpha + c \pm \sqrt{\gamma(2\alpha - \gamma - 2c)} \right) \quad (2.46)$$

To have a solution to the polynomial function $f(\cdot)$, the discriminant has to be positive:

$$\gamma(2\alpha - \gamma - 2c) \geq 0 \quad (2.47)$$

Rewriting 2.47 we obtain

$$\frac{\gamma}{2} \leq \alpha - c \quad (2.48)$$

This inequality holds always under Assumption (A.1).

To verify the conditions in 2.43, signalling price p^s must be element of sets of intervals, i.e. $p^s \in [p(c)_1; p(c)_2] \cap ((-\infty; p(0)_1] \cup [p(0)_2; +\infty))$. Because of the cost difference between the varieties, the separating price must belong to the interval $[p(0)_2; p(c)_2]$, which corresponds to $\left[\frac{1}{2} \left(\alpha + \sqrt{\gamma(2\alpha - \gamma)} \right); \frac{1}{2} \left(\alpha + c + \sqrt{\gamma(2(\alpha - c) - \gamma)} \right) \right]$.

At the lower bound, $p^s = \frac{1}{2} \left(\alpha + \sqrt{\gamma(2\alpha - \gamma)} \right)$, the profit distortion of the HEQ from signalling is minimal, which is the lowest upward distortion of the price necessary

to discourage the LEQ from mimicking the clean variety. Note that the signalling price of the clean variety is linked to the dirty variety's marginal cost.

Case 20 2: *signalling high environmental quality under the environmental regulation*

Same as in case 1 except that in the interval $P_{IC} = (-\infty; p(t)_1] \cup [p(t)_2; +\infty)$, the roots $p(t)_{1,2} = \frac{1}{2} \left(\alpha + t \pm \sqrt{\gamma(2(\alpha - t) - \gamma)} \right)$ taking into account the emission permit price as entering the marginal cost function of the dirty variety.

Proof of Corollary 12: the sign of $\frac{\partial p^s}{\partial c(\underline{e})}$.

Proof. Let $c_e < 0$, then $\frac{\partial p^s}{\partial c(\underline{e})} = \frac{1}{2} \left[1 + \frac{\gamma}{\sqrt{\gamma(2\alpha - \gamma - 2c(\underline{e}))}} \right] > 0$ for all parameter values. Let $c_e > 0$, then $\frac{\partial p^s}{\partial c(\underline{e})} = \frac{1}{2} \left[1 - \frac{\gamma}{\sqrt{\gamma(2\alpha - \gamma - 2c(\underline{e}))}} \right]$. Suppose its sign is negative, then:

$$\gamma < \sqrt{\gamma(2\alpha - \gamma - 2c(\underline{e}))} \quad (2.49)$$

As both sides of inequality (2.49) are positive, taking square and rearranging gives:

$$2\gamma(\alpha - \gamma - c(\underline{e})) < 0 \quad (2.50)$$

Given $\gamma > 0$, (2.50) violates Assumptions (A.1). ■

2.7.2 Consumers entirely internalize the pollution externality

Let us briefly examine the outcome of optimal environmental regulation when consumers entirely internalize the pollution externality. Suppose that consumers' disutility from pollution correspond exactly to the objective (scientific) level of damage from pollution, i.e. $\delta = \gamma$. Hence, the regulator doesn't need to take into account the negative externality from pollution because consumers by their behavior have already accounted for it. Otherwise it would lead to a double/redundant according of the environmental damage

.Then, we can rewrite (2.23) to get:

$$W(t) = \mu \left(\alpha - \frac{1}{2} q^s(t) - c \right) q^s(t) + (1 - \mu) \left(\alpha - \gamma - \frac{1}{2} q_d^f(t) \right) q_d^f(t) \quad (2.51)$$

The corresponding first order condition, when replacing $q_d^f(t)$ by $\frac{\alpha - \gamma - t}{2}$ and $q_d^{f'}(t)$ by $-\frac{1}{2}$, is given by $\mu q^{s'}(t) (p^s(t) - c) - \frac{1}{4} (1 - \mu) q_d^{f'}(t) (\alpha - \gamma + t) = 0$. If the regulator knows that the negative externality from pollution is internalized, he must use permit market to correct the monopoly distortion and the informational distortion. Substituting $-\frac{1}{2} \left(1 \mp \sqrt{\frac{\gamma}{2\alpha - \gamma - 2t}} \right)$ for $q^{s'}(t)$ for weak and strong regulation respectively and rewriting the above first order condition we obtain the implicit form of the optimal permit price:

$$t_e^* = -(\alpha - \gamma) - 2 \frac{\mu}{1 - \mu} \left(1 \mp \sqrt{\frac{\gamma}{2\alpha - \gamma - 2t}} \right) (p^s(t) - c) \quad (2.52)$$

The expression in (2.52) is negative for weak and strong regulation¹⁹. When $\delta = \gamma$, the regulator would need to subsidy the producer to correct the distortions in the economy. It is almost intuitive that when polluting externality has been internalized there is no room for tis correction. The environmental regulation is incapable of improving welfare.

2.7.3 The choice of optimal pricing

Comparison between pooling and separating profits

The pooling profit for a producer's type e is:

$$\pi^p(p, e, \mu_0) = (p - c(e)) (\alpha - \gamma (\bar{e} - \mu_0) - p) - F(e) \quad (2.53)$$

¹⁹The expression $-\frac{1}{2} \left(1 - \sqrt{\frac{\gamma}{2\alpha - \gamma - 2t}} \right) < 0$ given Assumption (A.3).

The price that maximizes π^p for each type e is:

$$p^{p*} = \max_p \pi^p(p, e, \mu_0) \quad (2.54)$$

$$= \frac{1}{2} [\alpha - \gamma(\bar{e} - \mu_0) + c(e)] \quad (2.55)$$

The maximal profit under pooling is thus:

$$\pi^{p*}(p^{p*}; e, \mu_0) = \frac{(\alpha - \gamma(\bar{e} - \mu_0) - c(e))^2}{4} - F(e) \quad (2.56)$$

The profit of the clean firm under separation is given by (2.57). Replacing p by (2.12) yields the singling profit that effectively reveals high environmental quality:

$$\begin{aligned} \pi^s(p^s; \bar{e}, 1) &= \frac{1}{4} \left(\alpha - c(\underline{e}) - \sqrt{\gamma(2\alpha - \gamma - 2c(\underline{e}))} \right) \\ &\quad \times \left(\alpha - 2c(\bar{e}) + c(\underline{e}) + \sqrt{\gamma(2\alpha - \gamma - 2c(\underline{e}))} \right) - F(e) \end{aligned} \quad (2.57)$$

For the exposition purpose, some simplification of notation is worthwhile. As fixed costs have solely a level effect, we set $F(e) = 0$. The effective difference in cost efficiency is crucial/ substantial for separation, thus we set $c(\underline{e}) = 0$ and $c(e) = c$ which measures now on the difference between effective production marginal costs of the dirty and the clean types.

To obtain the parameters under which the separating pricing is optimal, we solve for $\pi^s(\bullet) > \pi^p(\bullet)$ given the assumptions of the model. The solution yields:

$$\left[\begin{array}{l} 0 < c \leq (1 + \sqrt{2})\gamma \quad \wedge \quad 0 < \mu < \hat{\mu} \quad \wedge \quad c + \gamma < \alpha \leq \bar{\alpha} \\ \left\{ \begin{array}{l} (1 + \sqrt{2})\gamma < c < 4\gamma \\ \left[\begin{array}{l} 0 < \mu < \hat{\mu} \quad \wedge \quad c + \gamma < \alpha \leq \bar{\alpha} \\ \hat{\mu} < \mu < 1 \quad \wedge \quad \underline{\alpha} < \alpha \leq \bar{\alpha} \end{array} \right. \\ c \geq 4\gamma \quad \wedge \quad 0 < \mu < 1 \quad \wedge \quad \underline{\alpha} < \alpha \leq \bar{\alpha} \end{array} \right. \end{array} \right. \quad (2.58)$$

with $\hat{\mu}$ being a critical value for which $\bar{\alpha}$ and $\underline{\alpha}$ equal (their intersection doesn't belong to the area of product desirability);

$$\bar{\alpha} \equiv \frac{c^2(2-\mu)-2c\gamma(1-\mu)\mu+2c\sqrt{1-\mu}|c-\gamma\mu|+\gamma^2(2-\mu)\mu^2}{2\gamma\mu^2} \text{ and}$$

$\underline{\alpha} \equiv \frac{c^2(2-\mu)-2c\gamma(1-\mu)\mu-2c\sqrt{1-\mu}|c-\gamma\mu|+\gamma^2(2-\mu)\mu^2}{2\gamma\mu^2}$. For parameters given by (2.58) the signaling profit exceeds that of pooling.

Parameter conditions for full information price signaling Under separation, that is when the conditions of the individual rationality, IR_C , and incentives compatibility, IC_D , are verified and $\pi^s > \pi^p$, if $p^* \in \varrho_{IR} \cap \varrho_{IC}$, the full information price is informative and no distortion is required. Thus, we solve for $p^* = p^s$ conditional on (2.58) to obtain:

$$c > \left(1 + \sqrt{2}\right) \gamma \wedge \alpha \geq \frac{c^2 + \gamma^2}{2\gamma} \quad (2.59)$$

which determines the area of full information separating prices.

Proof of Claim 15: $\mu < \frac{1}{2}$.

Proof. For dirty variety with monopoly position the socially optimal environmental tax (Buchanan tax) requires that $p^* = c(\underline{e}) + \delta$. This result in $t^{Buch} = 2\delta - (\alpha - \gamma)$. For a positive tax must hold that $\delta > \frac{\alpha - \gamma}{2}$.

With probabilistic welfare and $\mu \geq \frac{1}{2}$, environmental damage must outweigh the social value of the clean variety. Taking the lowest bound of $\mu = \frac{1}{2}$ implies that $\delta \geq \alpha - \gamma$ which violates assumption A.3 for social desirability of conventional variety. ■

Demonstration: $\frac{\partial^2 W}{\partial t^2} < 0$

To ensure that t maximizes welfare, the second order condition must verify:

$$\frac{\partial^2 W(t)}{\partial t^2} = \mu \frac{\partial q}{\partial p^s} \left[\frac{\partial^2 p^s}{\partial t^2} (p^s - c(\bar{e})) + \left(\frac{\partial p^s}{\partial t} \right)^2 \right] + (1 - \mu) \frac{\partial q}{\partial p^*} \left(\frac{\partial p^*}{\partial t} \right)^2 < 0 \quad (2.60)$$

Given that $\frac{\partial q}{\partial p} < 0$ for both environmental types, it must hold that the second derivative of clean type's price margins is positive. It is so for downward price distortion as $\frac{\partial^2 p^s}{\partial t^2} = \frac{\gamma}{2[\gamma(2\alpha - \gamma - 2t)]^{3/2}} > 0$. For upward price distortion, the second derivative of price in t , $\frac{\partial^2 p^s}{\partial t^2} = \frac{-\gamma}{2[\gamma(2\alpha - \gamma - 2t)]^{3/2}}$, is negative. Therefore must hold:

$$\left(1 - \frac{\gamma}{\sqrt{\gamma(2\alpha - \gamma - 2t)}}\right)^2 \geq \frac{\gamma(p^s - c(\bar{e}))}{2[\gamma(2\alpha - \gamma - 2t)]^{3/2}} \quad (2.61)$$

Replace $\Upsilon \equiv \sqrt{\gamma(2\alpha - \gamma - 2t)}$, then (2.61) simplifies to:

$$\frac{1}{\Upsilon^2} (\Upsilon - \gamma)^2 \geq \frac{\gamma p^s - c(\bar{e})}{2\Upsilon^3} \quad (2.62)$$

$$(\Upsilon - \gamma)^2 \geq \frac{\gamma \alpha + t - 2c + \Upsilon}{4\Upsilon} \quad (2.63)$$

Given $\alpha - \gamma > t$, we have that $\frac{\gamma \alpha + t - 2c + \Upsilon}{4\Upsilon} < \frac{\gamma \alpha + t - 2c + \Upsilon}{4\Upsilon}$. Besides, for weak regulation $c > t$, thus $\frac{\gamma \alpha + t - 2c + \Upsilon}{4\Upsilon} < \frac{\gamma \alpha + t - 2c + \Upsilon}{4\Upsilon} = \frac{1}{4}(\Upsilon + \gamma)$. Replacing Υ and solving for α gives the following condition:

$$\alpha \geq \frac{1 + 8\gamma}{64\gamma} \left[\sqrt{1 + 32\gamma} + 1 + 16\gamma + 64\gamma t \right] \quad (2.64)$$

Using $c > t$ makes the condition more demanding:

$$\alpha \geq \frac{1 + 8\gamma}{64\gamma} \left[\sqrt{1 + 32\gamma} + 1 + 16\gamma + 64\gamma c \right] \quad (2.65)$$

This condition places the lower bound on α . It can be shown that for separating equilibrium with upward price distortion, it is not constraining (see Figure 2-4). On the plot, the bound restricts some area for the low values of α . This is because we set $t \rightarrow c^-$, which is for the weak regulation over constraining. It has been shown that for all tax values sufficiently close to c , the pooling equilibrium prevail. Reducing accordingly the slope of the line removes the constraining effect. Hence, for all separating equilibria with upward price distortion, the second order condition holds.

2.7.4 Proof of Corollary 16: $\frac{\partial t^*}{\partial \mu} < 0$

Proof. Recall that expression (2.25) is an implicit function:

$$\frac{\partial W(t)}{\partial t} \equiv F(t, \mu; \alpha, \gamma, \delta, c, e) = 0 \quad (2.66)$$

which is defined in the neighborhood of t^* . Using implicit-function rule, $\frac{dt}{d\mu} = -\frac{F_\mu}{F_t}$, note that F_μ and F_t correspond to $W_{t\mu}$ and W_{tt} . In (2.7.3) we've shown that $W_{tt} < 0$, to demonstrate negative relation of $\frac{dt}{d\mu}$ it is enough to have $F_\mu < 0$. Taking derivative of (2.25) with respect to μ we obtain:

$$F_\mu = \frac{\partial q}{\partial p} \frac{\partial p^s}{\partial t} (p^s - c(\bar{e})) - \frac{\partial q}{\partial p} \frac{\partial p^*}{\partial t} (p^* - c(\underline{e}) - \delta) \quad (2.67)$$

Since $\frac{\partial q}{\partial p} < 0$, the first term of the right hand side is negative. In the second term, the 'social' price margin is negative when FOC holds. Hence, $F_\mu < 0$. ■

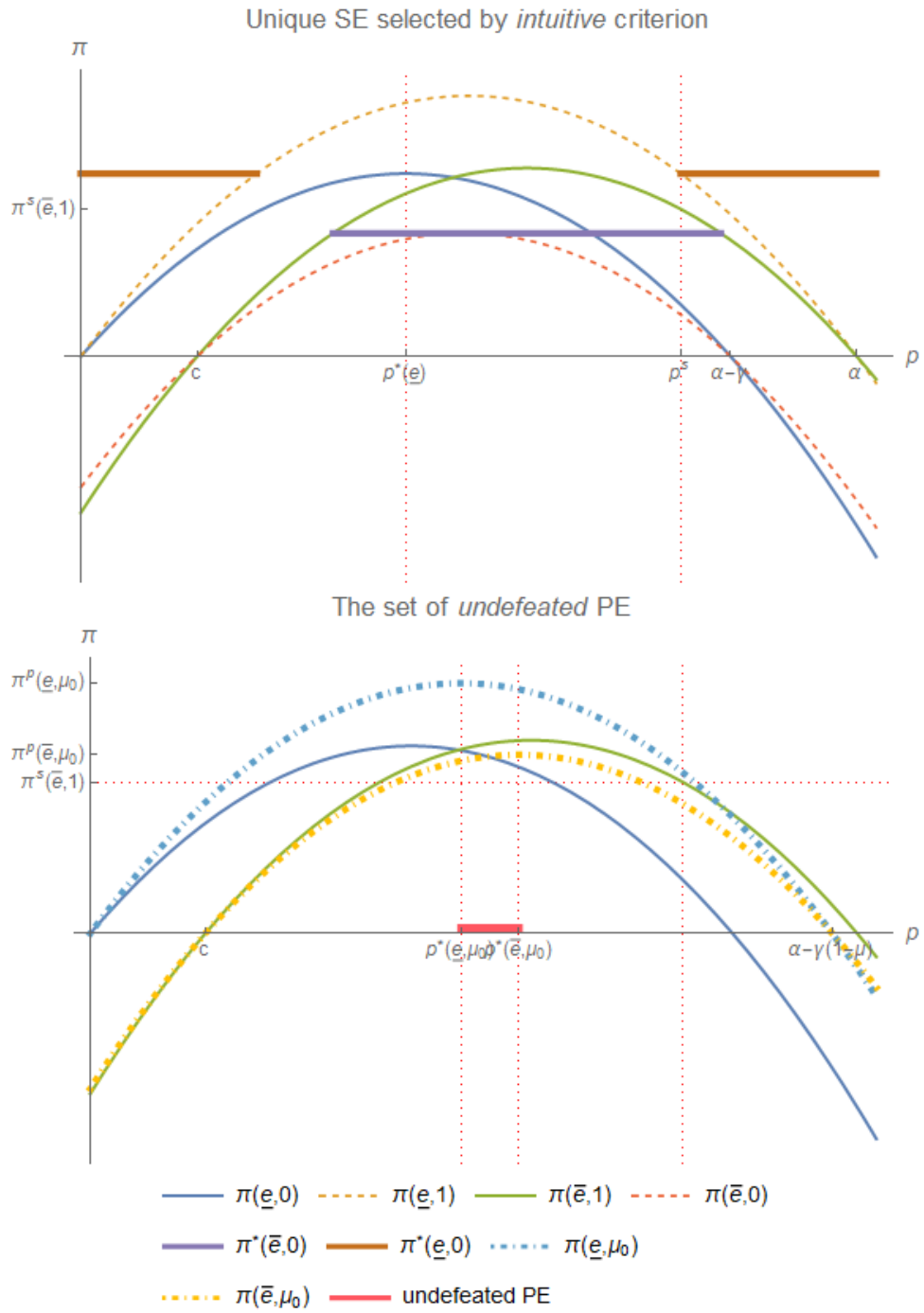


Figure 2-1: Equilibrium selection

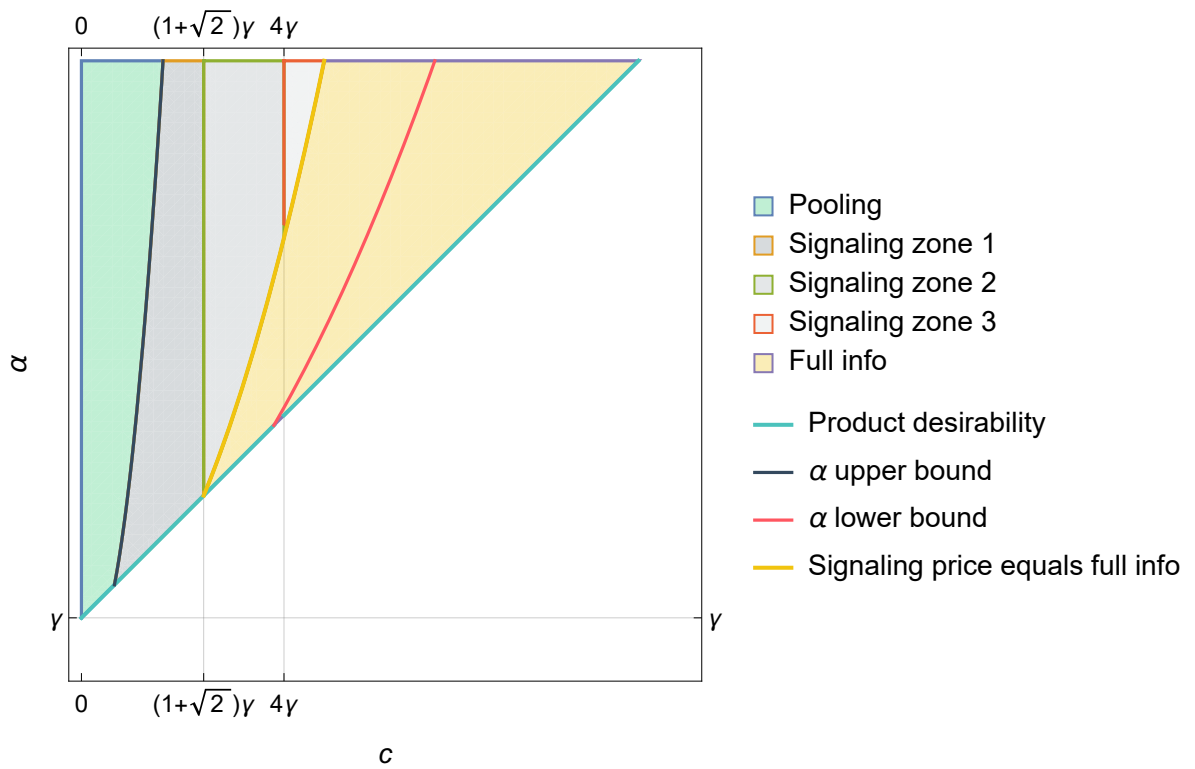


Figure 2-2: Parameter zones for optimal pricing

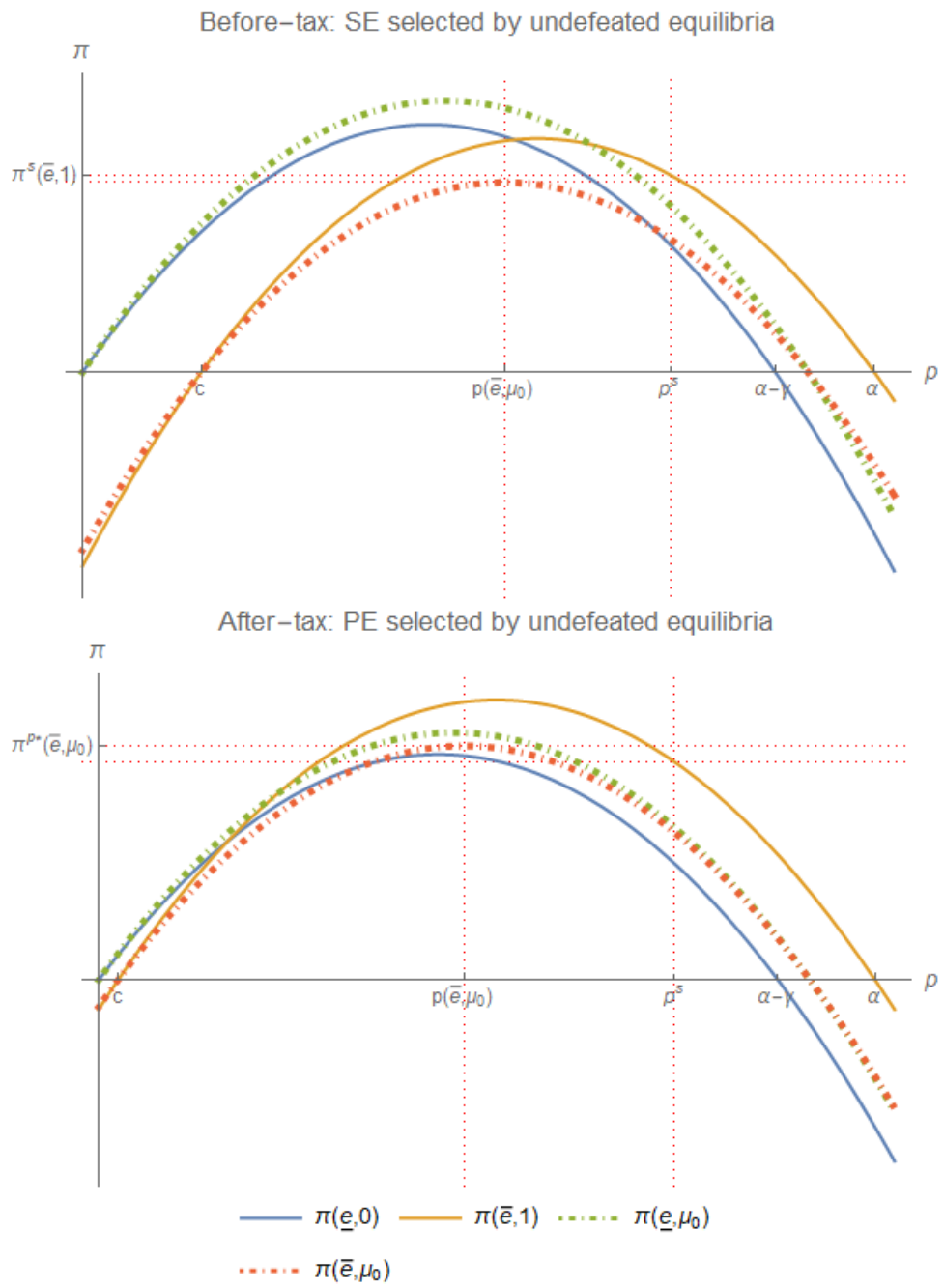


Figure 2-3: Equilibrium ‘migration’

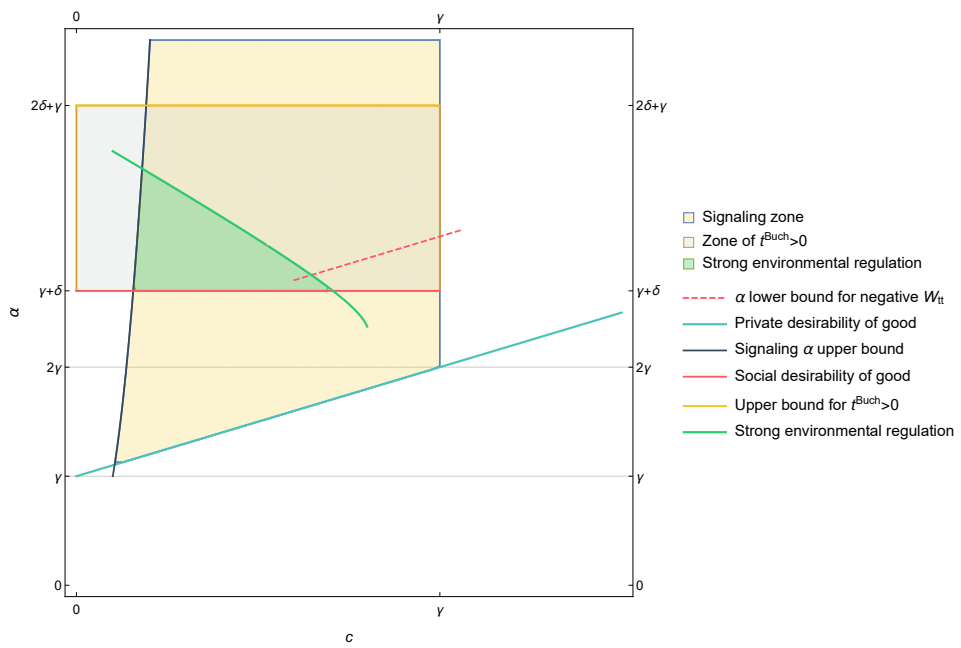


Figure 2-4: Zone of strong environmental regulation

Part III

Differentiation in environmental quality

Chapter 3

Taste for diversity, pollution aversion and optimal choice of environmental quality

In a stylized model of vertically differentiated brown-green duopoly, two firms compete in quantities. The baseline model derives the level of environmental quality determined solely by the green firm. We argue that this equilibrium might be unstable in the long run because the firms generate unequal profits. The possibility to coordinate their action allows the brown firm to benefit from a greater differentiation, and the green firm to preserve its leadership position in quality choice. We thus adjust the model to allow for producers' organization, also with environmental awareness. For every case under consideration, the privately chosen level of environmental quality falls short of the social optimum. Hence, in context of a global tendency of deregulation of markets, entrusting implementation of public interests to a private entity may call for caution.

Keywords: Vertically Differentiated Duopoly, Environmental Quality, Pollution Aversion

JEL Code: D43, D62, Q52

Résumé du chapitre 3

Le choix de la qualité environnementale est une décision stratégique pour l'entreprise.

La littérature établit que, du point de vue d'un régulateur bienveillant, un agent privé choisit un niveau de qualité environnementale sous-optimal (la qualité ayant les attributs d'un bien public). Le chapitre 3 comprend un modèle stylisé d'un duopole caractérisé par des producteurs de la qualité verte (i.e. relativement propre) et brune (i.e. conventionnelle) verticalement différenciés. Le pouvoir de marché est partagé entre les deux firmes qui se concurrencent en quantité. Ce pouvoir augmente avec la hausse de la qualité environnementale permettant une différenciation plus prononcée.

On part d'un modèle de référence dans lequel le niveau de qualité environnementale choisi est sous-optimal. Dans ces conditions, on s'interroge sur la durabilité et la stabilité de cette stratégie. L'équilibre est caractérisé par un profit plus faible pour la firme brune que pour la verte. N'ayant pas une possibilité d'une déviation profitable, le profit de la firme brune est pourtant strictement croissant en fonction de la qualité environnementale. La firme brune aurait intérêt à inciter sa concurrente à distordre son choix de qualité environnementale vers le haut. L'entreprise verte, à son tour, en anticipant la gêne de la firme brune concernant le rapport des profits, vise à s'assurer la position dictatrice en termes du choix de qualité environnementale sur le marché. L'objectif est de dissuader l'entreprise brune de toute tentative de déviation.

On étudie donc le choix optimal de qualité environnementale dans un cadre d'une organisation des producteurs qui permet aux entreprises de communiquer afin de se coordonner. Ce choix de long terme qui favorise l'intérêt mutuel n'assure pourtant pas un niveau de qualité environnementale socialement désirable.

Afin de tenir compte du dommage environnemental, on intègre au modèle la pression sociétale d'une organisation non-gouvernementale (ONG) sur les entreprises. Menaçant d'une publicité nocive, l'ONG peut inciter l'organisation des producteurs à internaliser leur empreinte environnementale dans la décision interne. On constate que cette mesure

n'atteint pas non plus le niveau de qualité environnementale socialement optimal. En effet, l'organisation ne prend pas en compte la valeur attribuée à la diversité des biens sur le marché par les consommateurs.

Cette défaillance nous renvoie aux questions principales suivantes : quel est le mécanisme d'incitation qui serait à la fois puissant et efficace ? Quels sont les coûts associés à la tentative d'accorder un rôle social à une structure privée ? Enfin, le marché correctement ajusté peut-il véritablement corriger les externalités ?

3.1 Introduction

In a stylized model of vertically differentiated brown-green duopoly, two firms with market power that rises in environmental quality are competing in quantities.

In a baseline model, we derive the privately supplied level of environmental quality and show, in line with the literature, that this level is suboptimal compared to what a benevolent regulator would desire. We argue that this equilibrium might be unstable in the long run because the firms generate unequal profits what provides an incentive to coordinate their action: for the brown firm to benefit from a greater quality differentiation, and for the green firm to ensure the leadership position in the choice of environmental quality.

We thus adjust the model to allow for producers' organization, also with environmental awareness induced by the threat of NGO's negative publicity. For every case under consideration, the privately chosen environmental quality falls short of the socially desirable level. Hence, in context of a global tendency of deregulation of markets, entrusting implementation of public interests to a private entity may call for caution.

Literature review Among most closely related literature, in the framework of a differentiated Bertrand duopoly (Amacher, Koskela, and Ollikainen 2004) study the optimal market choice of green technology investment. The firms' decision is contrasted to the socially optimal level of investment. Two versions of social optimum are considered: a standard utilitarian and one with environmental externality. The externality is positive and represents consumers' perception of an average environmental quality (EQ). The externality however does not imply any damage to the natural environment. The model has three stages with the investment, quality and price decisions being made successively and resolved by backward induction. The technology investment is assumed to reduce marginal cost. The fixed cost of the investment can be higher or lower for the high quality firm than for its low quality competitor. Thus all the strategic interactions are linked to the relative efficiency of the high quality firm. The resulting quality choices affect the

severity of competition. If the high quality firm is more efficient, she invests more than socially optimal in the environmental quality to relax price competition. However, since it is assumed that the investment also increases the willingness to pay for the product the resulting market quality is highest when low quality firm is efficient in investment because it takes more effort to relax price competition.

(Conrad 2005) analyzes the optimal EQ choice made by firms in the market of a horizontally differentiated duopoly with price competition. The author views EQ as a horizontal attribute. It is rather a matter of consumers' tastes than a sign of superior product quality. Indeed, EQ is often negatively related to intrinsic quality: polluting cars are more powerful, bleached or recycled paper is brighter and is seen as of a higher quality, organic vegetable or fruit have less visual flaws than conventional ones. This particular assumption renders the utility function (and the intrinsic reservation price) concave in EQ. The model is resolved by a two-step game. Depending on the relation between the dislike of pollution and the (private) cost of production, it can result in 3 quality spaces. When an extreme environmental concern is present, the duopolists choose the highest EQ and make zero profits. Lowering environmental concern, makes quality space and profits gradually increase. It turns out that for intermediate environmental concern, the quality space is always a corner solution.

(Mankiw and Whinston 1986) study the equilibrium number of firms in a free-entry oligopolistic market with a fixed cost investment at entry. In the baseline model - a Cournot oligopoly with homogenous goods - the market equilibrium is characterized by an excessive entry than is socially optimal. Each new entry increases welfare by the profit the new entrant obtains and reduces aggregate profits of competitors since they have to reduce their output (business stealing effect). Although the excessive entry is welfare decreasing, it doesn't have to be the correct measure of welfare loss. The welfare loss due to free entry however declines as the socially optimal number of firms increases. The result of excessive entry doesn't hold specifically for an oligopolistic market, it holds also for cartels where firms continue to entry until "*all* of the collusive monopoly profits are

dissipated into set-up costs". However, if consumers appreciate diversity of homogenous products, then each new entry has a positive effect on welfare since it increases the variety. Depending on which effect - business stealing or variety - dominates, the market equilibrium can result in excessive, insufficient or optimal number of firms. Ultimately, when the number of firms grows larger and firms come to act as price takers and if the set-up cost approaches zero, in that case the market equilibrium number of firms approaches the social optimum.

(Dixit 1979) develops a theory of entry barriers. In a Cournot duopoly, he points out that there are discontinuities in response function if market entry requires a fixed cost investment. The analysis of an incumbent firm reveals that threatened by an entry of a competitor, depending on the magnitude of the fixed costs, the incumbent may find it optimal to either accommodate or to deter entry. If the competitors fixed costs are so high than there is no entry. If they are low, the incumbent is better off accommodating entry because the deterrence strategy becomes excessively costly. If entrant's fixed costs are intermediate, the incumbent is better off deterring entry by producing limit quantity. Further, the author analyzes the circumstances to determine the facility of entry. He demonstrates that the increase in net private value (net advantage) of the incumbent variety hinders entry while a decrease in substitutability between goods facilitates entry.

3.2 The model

We wish to compare the level of environmental quality (EQ) that a firm chooses on the basis of profit maximization with the level that a benevolent welfare-maximizing regulator would desire.

We suppose that the market is composed of two producers that can supply brown and/or green EQ. The brown quality signifies a conventional production which emits polluting particles. The producer of brown variety has a conventional production technology that exerts polluting emissions. The producer of green EQ undertakes some abatement

effort and thus the production of a green product is characterized by less intense emissions. So the output of the two firms differs in the level of environmental cleanliness. As more abatement is undertaken, the more differentiated the products are, and thus less substitutable one for another.

We assume that despite pollution, both varieties are socially desirable. Let e denote the level of EQ chosen by the green producer, $e \in [0; 1]$. When $e = 0$, there is no abatement effort and emissions are proportional to the output, and the two products are equal, the competition is a duopoly of homogenous goods, when $e = 1$, the emissions are zero, the green and brown product attain the maximal differentiation which divides the market in two independent niches for each type of EQ. Thus, the level of abatement allows relaxing the competition intensity

The order of the baseline game is as follows: at Stage 1 the green producer chooses the profit-maximizing level of EQ e_g . At Stage 2, both producers participate in Cournot competition with differentiated varieties choosing profit-maximizing output. At Stage 3, consumers make their purchasing decisions.

We solve the game by backward induction.

The consumers' utility function is quasi-linear in all other goods in the sense/style of (Dixit 1979):

$$U(p_i, p_j, q_i, q_j, e_i, e_j) \equiv (a - (1 - e_i)d)q_i + (a - (1 - e_j)d)q_j - \frac{1}{2}(q_i^2 + q_j^2 + 2\gamma(e_i, e_j)q_iq_j) + I \quad (3.1)$$

with $\gamma(e_i, e_j)$ being a function that measures substitution between the goods q_i and q_j . To capture the idea that the more distinct the products are the less substitutable they are, a most 'neutral' function for γ is $\gamma(e_i, e_j) = 1 - |e_i - e_j|$. Indeed, if both firms choose zero abatement, their output is homogeneous in the eyes of consumers, then $\gamma = 1$. From the IO literature, we know that the producers would tend to - in the simplest and most basic model - maximally differentiate, this would result in, say, e_i choosing maximal

abatement and e_j choosing minimal abatement; in that case $\gamma = 0$ and both producers enjoy monopoly power. One could have thought of a more general substitution function of γ , as for example, $\gamma(e_i, e_j) = 1 - |e_i - e_j|^x$. Then for $x \in (0, 1)$, the substitution effect is amplified and for $x > 1$, the substitution effect is diminished. However, for our present purpose, let us stick to the most neutral version in terms of substitution effect and further let us suppose the firm i always chooses a higher abatement level compared to firm j (the results would be symmetric anyway). Since the tendency to differentiate products is an established fact in the IO literature, let us suppose that firm j is brown and she doesn't clean up the affluents from hers manufacturing/industrial activities while firm i chooses her level of abatement e_i , then:

$$U(p_i, p_j, q_i, q_j, e_i, 0) \equiv (a - (1 - e_i)d)q_i + (a - d)q_j - \frac{1}{2}(q_i^2 + q_j^2 + 2[1 - e_i]q_iq_j) + I \quad (3.2)$$

Let a measure the gross reservation price for each product type, indexes $i, j = \{b, g\} : i \neq j$ indicate the level of EQ for each product: brown or green; d describes consumers' taste for green EQ, $d > 0$; q_i indicates the number of units of i type's product that consumers purchase at price p_i with some income I . The last term, $(1 - e_g)q_iq_j$, specifies the degree of differentiation between the two products, that is the green producer optimally chooses the level of differentiation (or substitutability) with the rival product. This term can be viewed also as consumers' taste for variety, that is, the provision of similar varieties reduce consumers' utility.

From (3.2) we derive demand for k^{th} good/variety with $k = i, j$. Then, the quantity of good k consumed depend on/the demand is a function of k^{th} variety's price, $-k^{th}$ variety's output weighed by the abatement intensity of firm i . and k^{th} own level level of EQ:

$$q_k(p_k, e_k, q_{-k}; e_i) = a - (1 - e_k)d - p_k - (1 - e_i)q_{-k} \quad (3.3)$$

where $-k$ denotes the competitor of k .

Hence the level of EQ affects the demand in two ways. First, it measures consumers' willingness to pay for i^{th} variety. Second, the green variety's choice of EQ determines the level of demand: the more differentiation there is, the greater the demand is.

Since the dirty type doesn't abate pollution by assumption, e_b is set to zero and $e_g = e$. Replacing q_i by $\{b; g\}$ and q_j by $\{g; b\}$ respectively, where b and g represent quantities of brown and green products, we can obtain from (3.1) the inverse demand for the brown product:

$$P_b(b, g, e_g) = a - d - b - (1 - e)g \quad (3.4)$$

we emphasize that e is the level of EQ that the green producer optimally sets. The inverse demand for the green variety is given by:

$$P_g(g, b, e) = a - (1 - e)d - g - (1 - e)b \quad (3.5)$$

For the sake of simplicity we assume that marginal production costs of either green or brown are equal, and thus can be set to zero with no loss of generality. Assume further that the provision of high EQ requires a fixed investment, $F(e)$. $F(e)$ is continuous, twice differentiable and increasing and convex in EQ:

$$F(0) = 0, \quad F'(e) > 0, \quad F''(e) > 0 \quad (A.1)$$

Suppose that per unit cost is independent of environmental level.

Then, the profit the green firm earns is:

$$\pi^g(g, b, e) = P_g(g, b, e)g - F(e) \quad (3.6)$$

$$= [a - (1 - e)d - g - (1 - e)b]g - F(e) \quad (3.7)$$

Maximizing profit with respect to green variety's output, g , that gives the first order

condition (FOC) for the green firm:

$$\frac{\partial \pi_g}{\partial g} = \frac{\partial P_g}{\partial g} g + P_g = 0 \quad (3.8)$$

$$g(b) = -\frac{P_g}{P'_g(g)} = P_g(\bullet) \quad (3.9)$$

The FOC in (3.9) allows to state explicitly the reaction function of the green product to the brown firm's output::

$$g(b) = \frac{1}{2} [a - (1 - e) d - (1 - e) b - c(e)] \quad (3.10)$$

The brown firm's profit is:

$$\pi_b(b, g, e) = P_b(b, g, e) b \quad (3.11)$$

$$= [a - d - b - (1 - e) g] b \quad (3.12)$$

Similarly, the brown firm's FOC requires that:

$$\frac{\partial \pi_b}{\partial b} = \frac{\partial P_b}{\partial b} b + P_b = 0 \quad (3.13)$$

$$b(g) = -\frac{P_b}{P'_b(b)} = P_b(\bullet) \quad (3.14)$$

The corresponding reaction function is:

$$b(g) = \frac{1}{2} (a - d - (1 - e) g) \quad (3.15)$$

Solving the reaction functions allows obtaining equilibrium quantities of green and brown products. The equilibrium output for the brown variety is given by:

$$\begin{aligned} b^*(e) &= \frac{(1 + e) a - (1 + 2e - e^2) d}{3 + 2e - e^2} \\ &= \frac{a - d + (a - 2d) e + de^2}{(3 - e)(1 + e)} \end{aligned} \quad (3.16)$$

We assume that $\frac{\partial b^*}{\partial e} > 0$ imposing restrictions between parameters a and d :

$$\frac{\partial b^*}{\partial e} = \frac{a(e+1)^2 - 4d(1-e)}{(3-e)^2(1+e)^2} > 0 \quad (\text{A.2})$$

Note that the second derivative is strictly positive for all admissible values:

$$\frac{\partial^2 b^*}{\partial e^2} = \frac{d}{(e+1)^3} + \frac{2a+d}{(3-e)^3} > 0 \quad \forall e \in [0; 1] \quad (3.17)$$

Thus, $b(e)$ is increasing and convex in e .

The equilibrium profit of the brown variety given a level of e is:

$$\begin{aligned} \pi^{b^*}(e) &= \left(\frac{(1+e)a - (1+2e-e^2)d}{3+2e-e^2} \right)^2 \\ &= b^*(e)^2 \end{aligned} \quad (3.18)$$

Clearly, π_b^* is strictly increasing in the level of EQ that the green producer determines as the sign of $\frac{\partial \pi_b^*}{\partial e}$ corresponds to that of $\frac{\partial b}{\partial e}$, hence:

$$\frac{\partial \pi_b^*}{\partial e} = 2b(e) \frac{\partial b}{\partial e} > 0 \quad (3.19)$$

The equilibrium demand for the green variety given a quality choice e is:

$$\begin{aligned} g^*(e) &= \frac{(1+e)a - (1-e)d}{3+2e-e^2} \\ &= \frac{a-d + (a+d)e}{(3-e)(1+e)} \end{aligned} \quad (3.20)$$

Equilibrium profit of the green firm can be stated as:

$$\pi^g(g^*(e), e) = P_g(g^*(e), b^*(e), e) g(e) - F(e) \quad (3.21)$$

Note that the equilibrium output of the green variety is strictly increasing in the EQ:

$$\frac{\partial g^*}{\partial e} = \frac{1}{2} \left(\frac{2a + d}{(e - 3)^2} + \frac{d}{(e + 1)^2} \right) > 0 \quad (3.22)$$

The second derivative of green output is strictly negative for all admissible parameter values:

$$\frac{\partial^2 g^*}{\partial e^2} = -\frac{2a + d}{(e - 3)^3} - \frac{d}{(e + 1)^3} < 0 \quad (3.23)$$

Hence, g is increasing and concave in $e \in [0; 1]$.

The equilibrium profit of the green type is given by:

$$\begin{aligned} \pi^{g^*}(e) &= \left(\frac{(1 + e)a - (1 - e)d}{3 + 2e - e^2} \right)^2 - F(e) \\ &= g^*(e)^2 - F(e) \end{aligned} \quad (3.24)$$

If the firms chose not to diversify their products, the equilibrium profit of undifferentiated duopoly for $\forall e \in [0; 1]$ is:

$$\max_{q_i} \pi^g(q_i, q_i, e) = \frac{(a - d(1 - e))^2}{9} - F(e) \quad (3.25)$$

To exclude monopoly solution, assume that for $\forall e \in [0; 1] \quad \exists e \equiv \hat{e} :$

$$\frac{(a - (1 - \hat{e})d)^2}{9} - F(\hat{e}) = \frac{(a - d)^2}{9} \quad (A.3)$$

Assumption (A.3) states that there is an intermediate level of EQ at which the profits of undifferentiated green duopoly fall short of the profits of the undifferentiated brown duopoly. This implies that the fixed cost necessary to attain the split of the duopoly in two monopolies is too high.

As discussed earlier, both the green and the brown firms emit pollution. Let D denote

the corresponding environmental damage function from i^{th} variety, then:

$$D(q_i) = \delta(1 - e_i)q_i \quad (\text{A.4})$$

where δ denotes marginal damage per unit of output. It is clear that for the brown variety the emissions are equal to the output of brown units, while for the green variety, the emissions are reduced by the abatement effort defined by $e_g = e$.

Assumption (A.5) implies that disutility from pollution together with environmental damage outweighs the cost of EQ provision:

$$d + \delta > c'_e \quad (\text{A.5})$$

hence it is socially efficient to produce high EQ.

3.3 Short-term choice of EQ

In this section, we examine the optimal choice of EQ by the green firm.

In line with a standard approach in the literature, the green type will autonomously choose such level of e^* that maximizes its own profit in anticipation of subsequent quantity competition on the product market against the brown variety, thus:

$$e^* = \arg \max_e \pi^g(g(e), e) \quad (\text{3.26})$$

The FOC for (3.26) in e must solve the equation:

$$\begin{aligned} \frac{\partial \pi^g}{\partial e} &= 0 \\ 2g^*(e) \frac{\partial g^*}{\partial e} - F'(e) &= 0 \end{aligned} \quad (\text{3.27})$$

With the general form of (3.27) being:

$$\begin{aligned} \left[\frac{\partial P_g}{\partial e} + \frac{\partial P_g}{\partial b} \frac{\partial b}{\partial e} + \frac{\partial P_g}{\partial g} \frac{\partial g}{\partial e} \right] g(e) + P_g(\bullet) \frac{\partial g}{\partial e} - F'(e) &= 0 \\ \frac{\partial g}{\partial e} \left[\frac{\partial P_g}{\partial g} g(e) + P_g(\bullet) \right] + \left[\frac{\partial P_g}{\partial e} + \frac{\partial P_g}{\partial b} \frac{\partial b}{\partial e} \right] g(e) - F'(e) &= 0 \end{aligned} \quad (3.28)$$

The first term in (3.28) is zero since it is the FOC in quantity for the green product, i.e., $\pi^{g'}(g)$. Hence, the FOC in e reduces to:

$$\left[\frac{\partial P_g}{\partial e} + \frac{\partial P_g}{\partial b} \frac{\partial b}{\partial e} \right] g(e) = F'(e) \quad (3.29)$$

Equation (3.29) specifies the condition that maximized the profit of the green firm in anticipation of a Cournot competition against the quality differentiated brown variety.

This private choice of optimal EQ takes into account the impact the variation of e on prices of the green and the brown varieties. This reflects consumers' taste for EQ and the diversity of the green product.

Figure (3-1) depicts the profits of green (green color) and brown (red) firms as functions of EQ e .

3.4 Social choice of environmental quality

In this section, we examine what is the optimal choice of EQ in the eyes of a welfare-maximizing benevolent regulator. His objective is to maximize the standard utilitarian welfare function composed of consumers' and producers' surpluses and the environmental damage stemming from firm's output.

Hence, the regulator keeping in mind the difference in pollution intensity of the firms,

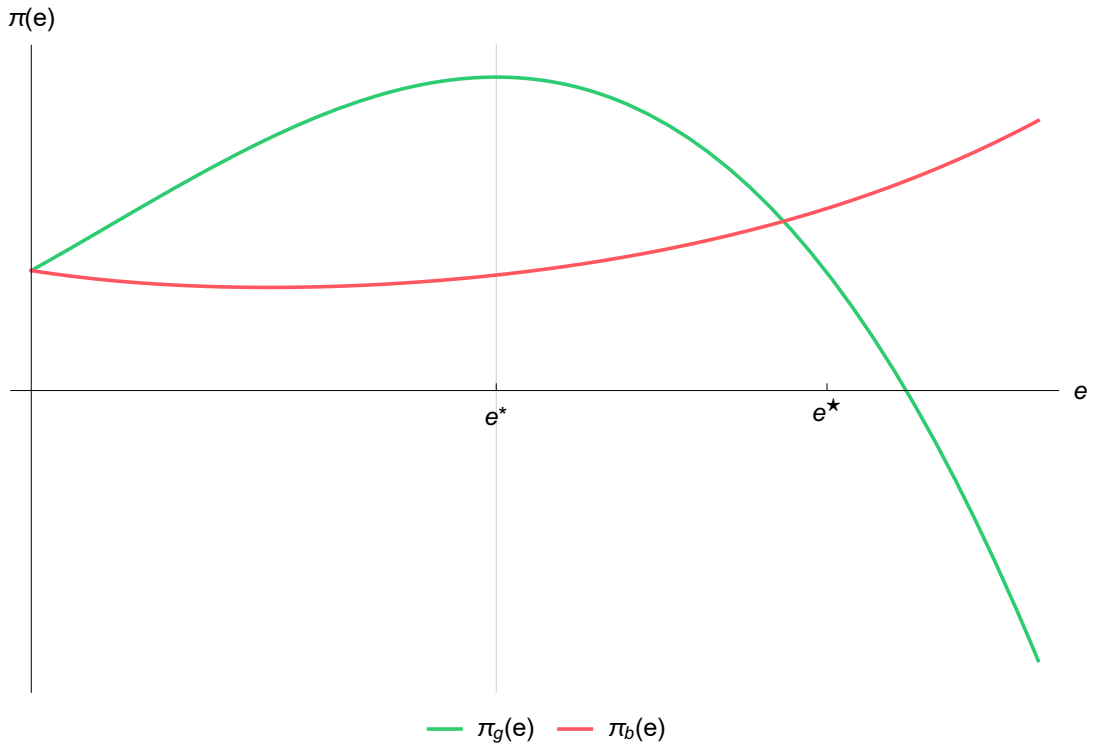


Figure 3-1: The choice of EQ by the green producer

has the following objective function:

$$\max_e W(e) = \int_0^{g(e)} P_g(b(t), g(t), t) dt - F(e) + \int_0^{b(e)} P_b(b(t), g(t), t) dt - \delta [(1-e)g(e) + b(e)] \quad (3.30)$$

which can be rewritten explicitly for $W(e)$ as:

$$\begin{aligned} & \left(a - (1-e)d - \frac{1}{2}g(e) - (1-e)b(e) - \delta(1-e) \right) g(e) - F(e) \\ & + \left(a - d - \frac{1}{2}b(e) - (1-e)g(e) - \delta \right) b(e) \end{aligned} \quad (3.31)$$

Using the FOC in (3.14) and (3.9), the social FOC specifies the socially desired level

of environmental quality:

$$\begin{aligned}
 & g'(e) [P_g(\bullet) - \delta(1 - e) - b(e)(1 - e)] + b'(e) [P_b(\bullet) - \delta - g(e)(1 - e)] \\
 + & g(e)(d + \delta) + g(e)P_b(\bullet) + b(e)P_g(\bullet) - F'(e) = 0
 \end{aligned} \tag{3.32}$$

Let e^\star denote the socially optimal level of EQ that solves (3.32), i.e., $e^\star = \arg \max_e W(e)$. Then, it is straightforward that e^\star must break-even the gains and the costs of the environmental quality provision at the social level.

An increase in e enhances the output of both varieties, hence the pollution; relaxes the competition and thus allows both producers to raise prices. Moreover, it satisfies consumers taste for high EQ and the diversity of products sold in the market.

Figure (3-2) illustrates the position of e^\star relative to e^* to emphasize the gap between socially and privately chosen levels of EQ.

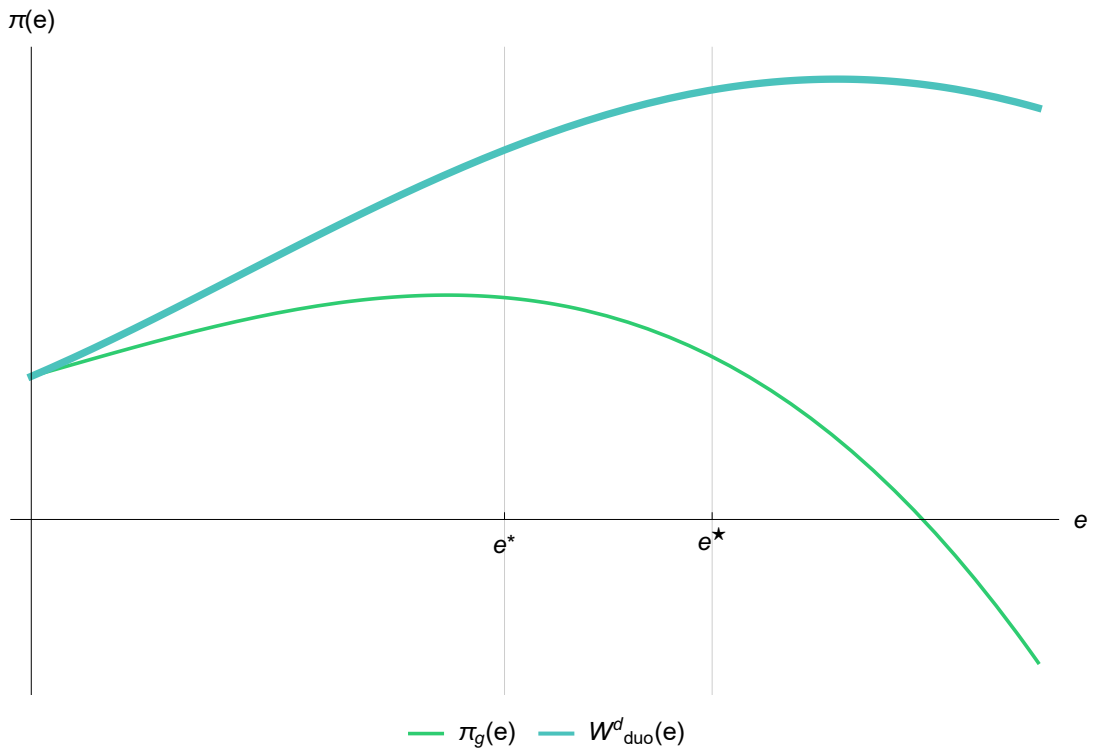


Figure 3-2: Socially optimal choice of EQ

Proposition 21 *The green firm driven by private interests supplies an insufficient level of EQ compared to the social optimum.*

In line with standard results, the private solution of EQ provision is below of what is socially desirable. The firm makes a myopic quality choice because it considers solely its private benefit from an increase of EQ.

3.5 Long-term private choice of environmental quality

Let us return to Figure (3-1) to examine the ‘durability’ of the equilibrium in $e = e^*$ derived in Section (3.3).

Note that the equilibrium choice e^* always gives the green firm a greater profit compared to the brown firm (this holds always provided that the green firm’s profit is concave in e , while π^b is convex). Although there is no profitable deviation for the brown firm, its profit is strictly increasing in e . It is clear that the ideal EQ in the eyes of the brown firm is $e = 1$. However, Assumption (A.3) excludes this possibility, rendering this option too costly.

Thus, the difference in profits of the two firms suggests certain instability of the equilibrium at $e = e^*$. If only the firms could communicate with each other facilitating a transfer that would equalize their profits, it would result in a long run stable equilibrium. In this setting, the brown firm has no longer any incentive to deviate, while the green firm ensures itself the leadership in the strategic choice of EQ.

Suppose that the producers can unite within a producers’ organization that represents their mutual interests with the goal to maximize joint profit (under condition of equal profits). Denote T the amount that the green firm transfers to the brown firm. Then the

joint objective function is:

$$\begin{aligned}\pi_j(b(e), g(e), e) &= \mu\pi_g(\bullet) + (1 - \mu)\pi_b(\bullet) \\ \text{s.t. } \pi_g(\bullet) - T &= \pi_b(\bullet)\end{aligned}\tag{3.33}$$

Where μ measures the weight of the green firm's interests within the producers' organization. The transfer cancels out in the objective function. Then, the FOC requires the following:

$$\begin{aligned}(1 - \mu) \left(\left[\frac{\partial P_b}{\partial e} + \frac{\partial P_b}{\partial b} \frac{\partial b}{\partial e} + \frac{\partial P_b}{\partial g} \frac{\partial g}{\partial e} \right] b + P_b \frac{\partial b}{\partial e} \right) + \\ \mu \left(\left[\frac{\partial P_g}{\partial e} + \frac{\partial P_g}{\partial b} \frac{\partial b}{\partial e} + \frac{\partial P_g}{\partial g} \frac{\partial g}{\partial e} \right] g + P_g \frac{\partial g}{\partial e} \right) = 0\end{aligned}\tag{3.34}$$

Substitute the FOCs from profit maximization, $\frac{\partial \pi_i}{\partial e}$ for $i = \{b, g\}$ for P_i , the condition () reduces to:

$$(1 - \mu) \left[\frac{\partial P_b}{\partial e} + \frac{\partial P_b}{\partial g} \frac{\partial g}{\partial e} \right] b + \mu \left[\frac{\partial P_g}{\partial e} + \frac{\partial P_g}{\partial b} \frac{\partial b}{\partial e} \right] g = 0\tag{3.35}$$

Condition (3.35) specifies the jointly chosen e^\star serving mutual interests.

Figure (3-3) illustrates the jointly chosen level of EQ.

Proposition 22 *Producers' mutual choice of EQ is below of what is socially desirable.*

When the producers chose the EQ determined by their joint interests, they take into account how the variation in e affects the prices as well as the equilibrium output of each variety.

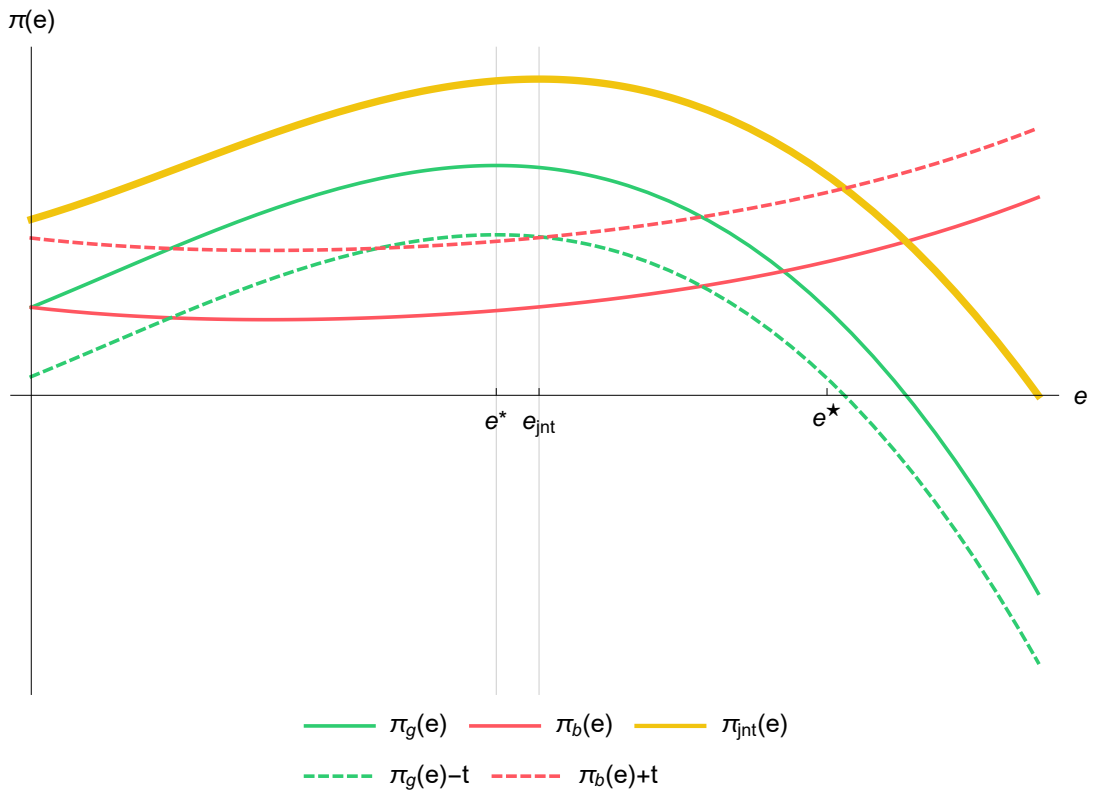


Figure 3-3: Choice of EQ by producers' organization

3.6 Producers' organization with environmental awareness

We devote this section to the analysis of the role of an NGO when it undertakes the engagement to advocate public interests.

The general tendency for globalization and deregulation has let the NGOs occupy a central position to influence public opinions. The NGOs have gotten down to fill up the gaps for which public authorities fail to reach.

The following passage captures the essential role of the NGOs when challenging large businesses:

"Aided by advances in information and communications technology, NGOs have helped to focus attention on the social and environmental externalities of business activity."

Multinational brands have been acutely susceptible to pressure from activists and from NGOs eager to challenge a company's labour, environmental or human rights record. Even those businesses that do not specialize in highly visible branded goods are feeling the pressure, as campaigners develop techniques to target downstream customers and shareholders.

In response to such pressures, many businesses are abandoning their narrow Milton Friedmanite shareholder theory of value in favour of a broader, stakeholder approach which not only seeks increased share value, but cares about how this increased value is to be attained.

Such a stakeholder approach takes into account the effects of business activity - not just on shareholders, but on customers, employees, communities and other interested groups.

There are many visible manifestations of this shift. One has been the devotion of energy and resources by companies to environmental and social affairs. Companies are taking responsibility for their externalities and reporting on the impact of their activities on a range of stakeholders.

Nor are companies merely reporting; many are striving to design new management structures which integrate sustainable development concerns into the decision-making process."¹

Despite a decade-long partnership between the Coca-Cola company and the World Wildlife Fund (WWF)² to help conserve world's freshwater resources, the Greenpeace has initiated several severe public campaigns against the Coca-Cola company. The essence of which is summarized in Figure (3-4)³.

¹ "The rise and role of NGOs in sustainable development", <http://www.iisd.org/business/ngo/roles.aspx>

² "A Transformative Partnership to Conserve Water: The Coca-Cola Company and WWF 2016 Annual Report", <https://www.worldwildlife.org/publications/a-transformative-partnership-to-serve-water-the-coca-cola-company-and-wwf-2016-annual-report>

³ Image credits. Left: "5 Reasons Why We're Outside Coca-Cola's HQ", 2017, <https://www.greenpeace.org.uk/5-reasons-why-greenpeace-are-outside-coke-hq/>.



Figure 3-4: NGO's campagne against Coca-Cola. Reprinted with permission from Greenpeace UK.

The goal of the NGO to spread negative publicity around the firm is to induce it to internalize its environmental footprint. Suppose that the costs from negative publicity represent the one-to-one mapping into environmental damage. Then, the producers' organization is forced to take the cost of polluting emission into account. Hence, rewriting the organization's objective function, we obtain:

$$\begin{aligned} \max_e W(e) &= \mu \pi^g + (1 - \mu) \pi^b - \delta [(1 - e) g(e) + b(e)] \\ \text{s.t. } \pi^g - T &= \pi^b \end{aligned} \quad (3.36)$$

Rewriting also the FOC for (3.36) gives:

$$\begin{aligned} (1 - \mu) \left[\frac{\partial P_b}{\partial e} + \frac{\partial P_b}{\partial g} \frac{\partial g}{\partial e} \right] b + \mu \left[\frac{\partial P_g}{\partial e} + \frac{\partial P_g}{\partial b} \frac{\partial b}{\partial e} \right] g \\ - \delta [(1 - e) g'(e) - g(e) + b'(e)] = 0 \end{aligned} \quad (3.37)$$

Right: "It's time to act - What can we do?", 2017, <https://www.greenpeace.org.uk/what-we-do/oceans/coke/>.

Denote e^\ddagger the level that solves for (3.37) and thus satisfy the joint firms' effort under the societal pressure of the NGO.

Figure (3-5) illustrates this equilibrium EQ choice relative to the social optimum.

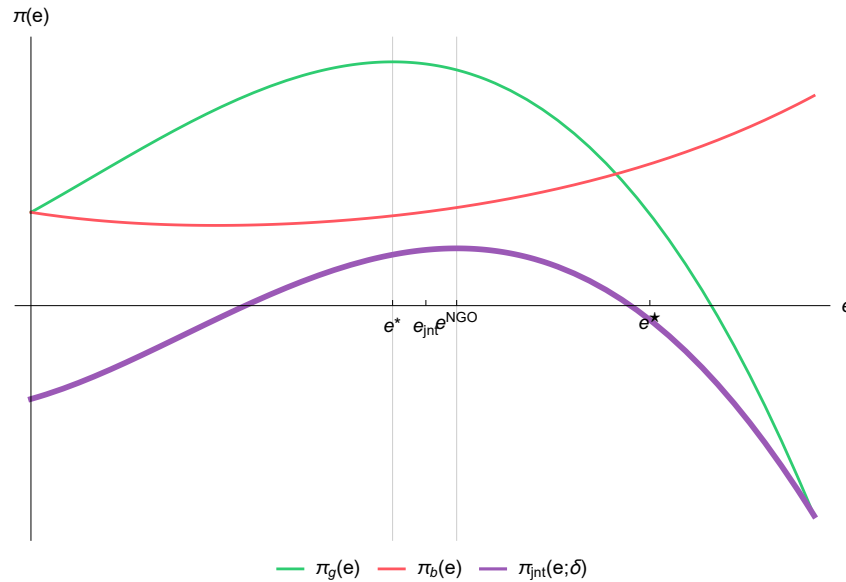


Figure 3-5: NGO's induced choice of EQ

Proposition 23 *The NGO induced choice of EQ is below social optimum.*

The reason why the joint firms' EQ choice falls short of the socially optimal level is that the producers' organization doesn't consider the surplus that consumers get from an enhanced EQ.

3.7 Conclusion

The article is to analyze the optimal choice of environmental quality when consumers value product diversity as well as high EQ.

We have derived the autonomous level of EQ chosen as a result of an environmental leadership by the green firm. Further, we've shown that a private entity has a tendency to fall short of the EQ level necessary from the point of view of the benevolent regulator.

These findings call for caution when a private entity is granted power to undertake the imposition of public interests. This initiative/ambition may be doomed to failure.

3.8 Appendix

3.8.1 The sequence of the game

At stage 1 both firms decide whether to invest in green production technology or not. At Stage 2 the green firm chooses its optimal level of EQ. At Stage 3, the firms compete in quantities in the product market.

Let us resolve the game by backwards induction.

At Stage 1 each firm must decide whether to make the green investment. Let us represent the profit in the tabular form:

		Firm 1	
		green	brown
Firm 2	green	$\pi_{1,g}^u, \pi_{2,g}^u$	$\pi_{1,g}^d, \pi_{2,b}^d$
	brown	$\pi_{1,b}^d, \pi_{2,g}^d$	$\pi_{1,b}^u, \pi_{2,b}^u$

Table (3.8.1) represent an input of the type π_{ij}^t that indicates the corresponding profits for firm $i = \{1, 2\}$ of environmental type $j = \{b, g\}$, i.e. brown or green. The upper superscript indicates the type t of the resulting duopoly, that is $t = \{u, d\}$ that is for undifferentiated or differentiated duopoly.

Given that consumers have green preferences, the green-green undifferentiated duopoly (Pareto) dominates the brown-brown undifferentiated duopoly.

At Stage 2, given the optimal EQ e set by the clean type, the two producers compete in quantities. This allows to write down profit and reaction functions.

Conclusion Générale

Cette thèse est structurée en trois chapitres analysant le rôle de la qualité environnementale comme une caractéristique intrinsèque d'un bien.

La qualité environnementale affecte les préférences des consommateurs, les stratégies des producteurs et le degré de sévérité de la réglementation environnementale. Cette thèse met en avant différents aspects du coût social de la pollution. La dégradation de l'environnement sensibilise les consommateurs à la qualité environnementale des produits, suscitant ainsi une certaine aversion envers les produits polluants. Une meilleure qualité environnementale est donc privilégiée. D'autre part, les producteurs considèrent la dimension environnementale d'un produit comme un moyen de différenciation, ce qui leur permet d'attirer des consommateurs supplémentaires. Finalement, la réglementation environnementale permet d'induire un niveau de pollution socialement optimal. Bien que j'ai principalement examiné une taxe incitative sur les émissions polluantes, j'envisage également la possibilité d'une intervention décentralisée, alternative à la régulation, par le biais des ONGs. Ainsi, cette thèse théorique se situe au croisement des domaines de l'économie publique et de l'économie industrielle au travers l'environnement.

Le premier chapitre traite de l'évasion fiscale du monopole polluant inhérent à une régulation environnementale. Dans une deuxième partie, la taxe sur les émissions d'un monopole potentiellement polluant et dont l'engagement environnemental est inobservable pour les consommateurs est endogénéisée. Le troisième article étudie la concurrence entre une entreprise propre et une entreprise polluante. Le choix décentralisé de la qualité environnementale est déterminé en fonction des intérêts d'une organisation de producteurs ou / et d'une ONG environnementale.

Généralement, l'aversion des consommateurs pour la pollution et leur préférence pour un produit d'une meilleure qualité environnementale internalise une partie du dommage environnemental. En même temps, elle (l'aversion) donne aux producteurs une incitation socialement indésirable à extraire le surplus dite vert des consommateurs. Dans

le cadre d'une concurrence imparfaite, les entreprises profiteront donc des préférences des consommateurs pour un environnement propre en exerçant leur pouvoir de marché. Cela rend la mise en œuvre de la réglementation environnementale plus coûteuse et plus problématique que dans une situation de concurrence parfaite.

Tout au long de cette thèse, la réglementation environnementale est basé sur seul dispositif – la taxe optimale du second degré sur les émissions polluantes. En effet, lorsque l'on considère plusieurs défaillances de marché (la pollution, la concurrence imparfaite, etc.), le résultat général prévoit que la taxe optimale doit être fixée en dessous du niveau Pigouvien. Il s'avère que si l'ensemble des défaillances du marché est corrigé par un seul dispositif, cela affaiblit à la fois le degré de sévérité et l'efficacité de la régulation environnementale. Il est clair que si l'on envisage un ensemble de dispositifs réglementaires pour confronter l'ensemble des défaillances du marché, il est, alors, possible d'atteindre un meilleur résultat en termes d'efficacité de coût et de qualité environnementale. On peut imaginer une séparation entre les buts environnementaux et ceux de mise en conformité en tant qu'un tel ensemble de dispositifs règlementaires. Lorsque, par exemple, une agence ou une ONG environnementale s'occupe de la qualité environnementale, le fisc est seulement responsable de l'imposition et de l'exécution de la taxation. Cependant, cette approche poserait inévitablement le problème de la coordination entre les organismes. Ceci suggère des perspectives possibles à cette thèse pour permettre une comparaison entre ces stratégies réglementaires et l'analyse de leurs limites et avantages.

Une autre perspective envisageable pourrait être une comparaison de l'efficacité d'une taxe environnementale et d'un dispositif de commande et de contrôle, comme des normes de qualité minimale ou des certifications de qualité obligatoire.

Je crois que la question de l'évasion fiscale environnementale en conjonction avec le pouvoir du marché ouvre tout un champ de recherche intéressant et d'actualité. La problématique serait alors de considérer le micro fondement du mécanisme d'évitement qui permettrait d'assurer la conformité à la régulation environnementale.

En outre, une problématique sur la réglementation environnementale d'une entreprise puissante (une multinationale) par plusieurs juridictions, ou une union d'états, serait une question de l'actualité. Bien que les états puissent partager un objectif commun sur le plan environnemental, ils peuvent également avoir des intérêts divergeant dans d'autres domaines, comme une concurrence fiscale ou différents points de vue sur la politique monétaire, d'emploi et de compétitivité. Le problème de coordination peut donc devenir un véritable obstacle à la régulation environnementale. La décision de la commission européenne lors de l'audition de l'affaire entre la société Apple, l'état d'Irlande et elle-même, représente un exemple dans le domaine de la fiscalité. Non seulement Apple bénéficiait d'un taux d'imposition plus favorable que ses concurrents, mais le gouvernement irlandais avait également refusé de réclamer les taxes précédemment dues et ce afin de garder leur bonne réputation en terme de fiscalité⁴.

Finalement, il serait intéressant de considérer, au lieu d'un monopole, un oligopole dans lequel les entreprises proposent l'optimisation de la taxe verte. Certes, la concurrence entre les entreprises limiterait leur capacité à extraire le surplus de consommateur mais ce même oligopole pourrait cumuler suffisamment de pouvoir pour faire du lobbying et ainsi obtenir des privilèges malgré la régulation environnementale. En effet, la possibilité du carbone leakage suite à l'introduction du système d'échange de quotas d'émission de l'UE (SEQE-UE) dans les secteurs énergivores a entraîné la sur-provision des quotas gratuits (grandfathering). De nombreuses entreprises ont ainsi obtenu grâce au commerce des quotas des bénéfices exceptionnels⁵. Cependant, jusqu'à présent le carbone leakage n'a pas été enregistré⁶, probablement au coût d'un prix du carbone insignifiant.

⁴ARTE, "*Fiscalité: quand l'Irlande s'oppose à l'Europe*", le 2 mai 2017, <https://info.arte.tv/fr/fiscalite-quand-lirlande-soppose-leurope>.

⁵Par exemple, Darby M., 2016, "*EU cement giants net €5bn carbon market windfall*", Climate Home News, <http://www.climatechangenews.com/2016/11/29/eu-cement-giants-get-e5bn-carbon-marché-aubaine/>

⁶Commission européenne, Action pour le climat, "*Carbon Leakage Evidence Project. Factsheets for selected sectors*", Rotterdam, le 23 Septembre, 2013"

General Conclusion

The thesis is composed of three chapters that analyze the role of environmental quality viewed as an intrinsic feature of a product.

Environmental quality affects consumers' preferences, producer's strategies and the stringency of environmental regulation. The analysis sheds light on different aspects of the social cost of pollution. Degrading natural environment pollution alters consumers' awareness of environmental quality forming certain aversion of environmentally dirty product, making consumers willing to spend a premium on environmentally superior quality. Producers view the environmental feature of a product as a means of product differentiation allowing to extract more of consumers' surplus. Environmental regulation is to incite socially optimal level of pollution. Although I mostly consider a tax on polluting emissions as an incentive instrument, I also explore a possibility of an alternative decentralized regulation/intervention by semi-public entities such as an NGO. Hence, the dissertation is theoretical and it reunites the domains of public and environmental economics with industrial organization.

The first article treats fiscal avoidance on the part of a polluting monopoly. The second endogenizes environmental taxation on emissions of a potentially polluting monopoly whose environmental engagement is unobservable to consumers. The third article allows competition between a clean and a polluting firms. The choice of environmental quality is decentralized and determined in accordance with the interests of a producers' organization or/and an environmental ONG.

Generally, consumers' aversion to pollution, their preferences for environmentally superior product endogenize by itself a part of pollution damage. At the same time it gives producers a socially undesirable incentive to extract the 'green' rent from consumers. Under imperfect competition, firms will take advantage from consumers' preferences for clean environment and will exercise market power. This renders the implementation of environmental regulation more costly and more problematic than it appears with perfect

competition.

Throughout the dissertation, the environmental regulation is mostly conducted with the help of a sole instrument - an environmental tax on polluting emissions. Indeed, when considering pollution, an imperfect competition and an additional market distortion, the general result is that the optimal second-best tax must be set below the Pigouvian level. It turns out that a number of market failures corrected by a means of an environmental taxation weakens both the stringency and the efficiency of the regulation. Clearly, a set of regulatory instruments is capable to improve the efficiency in terms of the cost and pollution control. One can imagine a separation within the regulatory entity as such a set. The separation can be achieved when, for example, an environmental agency or an environmental NGO is concerned with product's environmental quality and fiscal authority is in charge of the imposition and the enforcement of the tax. However, an inevitably problem that will arise is coordination. This suggests possible extensions to allow a comparison between these regulatory strategies and the analysis of their limits and advantages.

Another direction the extensions could take is to compare in the same framework the efficiency of a market-based environmental regulation against the command and control instruments as minimal quality standards, mandatory quality certification etc.

I believe that the matter of environmental tax avoidance in conjunction with market power opens up an entire fruitful and vital field of research. Most natural extension is to consider the micro foundation of the avoidance mechanism that would allow to formulate the enforcement scheme against 'environmental' fiscal avoidance.

Further developments that follow from the first chapter are to consider environmental regulation of a single powerful firm (a multinational) by a number of jurisdictions or states. Despite a common environmental goal the regulation may be subject to conflicting interests for the reasons of tax competition, different monetary policies or diverging objectives for employment and competitiveness. The court hearing between Apple, Ire-

land and the EU parliament can serve to illustrate the difficulty of coordination. Not only Apple used to benefit from a more favorable tax rate than his competitors, but also the government of Ireland has refused to collect the alleged difference in taxes due to protect the country's reputation for corporate friendly fiscal climate⁷.

Another natural extension would suggest to consider an oligopoly instead of a monopoly. On the one hand, this would limit the firms' capacity to extract rent but on the other, it may enable oligopolistic firms to unify forces to lobby for privileges within environmental regulation. As it has been the case during the EU emission trading system, the concerns of the possibility of carbon leakage in energy-intensive sectors has secured the supply of free pollution allowances (grandfathering) putting the industries in oversupply. Many firms thus have obtained windfall profits⁸ because of the trade of pollution allowances. So far there is no evidence of carbon leakage⁹, possibly at the cost of 'meaningful' carbon price that is still to achieve.

⁷ARTE, "*Fiscalité : quand l'Irlande s'oppose à l'Europe*", [*"Taxation : when Ireland is opposed to Europe"*], May 2, 2017, <https://info.arte.tv/fr/fiscalite-quand-lirlande-soppose-leurope>

⁸Darby M., 2016, "*EU cement giants net €5bn carbon market windfall*", Climate Home News, <http://www.climatechangenews.com/2016/11/29/eu-cement-giants-get-e5bn-carbon-market-windfall/>

⁹European Commission, DG Climate Action, "*Carbon Leakage Evidence Project. Factsheets for selected sectors*", Rotterdam, September 23, 2013

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Doctorat de l'Université de Montpellier

Faculté d'économie

Trois problèmes sur le marché d'un produit vert : évitement fiscal, signal et différenciation verticale

Résumé : La qualité environnementale ayant des caractéristiques d'un bien public fait objet de cette thèse. Dans un cadre théorique, on étudie d'abord les moyens de régulation d'une entreprise polluante et ensuite le choix décentralisé de la qualité environnementale. Pour une entreprise capable d'esquiver le fisc, la conformité à la taxation est déterminée en fonction du niveau de la taxe. Lorsque elle augmente, la non-conformité devient plus attractive. L'échappement fiscal modifie la composition de la taxe : elle prend en compte l'effet d'un comportement de passager clandestin de la firme et l'effet de l'érosion de l'assiette fiscale. La taxe optimale du second rang doit équilibrer ces deux effets opposés. Le comportement de passager clandestin rend le régulateur soit impuissant, soit inéquitable en fonction de la sévérité du dommage environnemental et de l'efficacité de l'entreprise. Dans un second temps, on étudie l'impact de la taxe environnementale sur la politique de prix d'un monopole qui utilise le signal en prix afin de communiquer aux consommateurs le haut niveau de qualité environnementale inobservable. On applique deux critères de sélection de l'équilibre : le critère intuitif et le critère d'invincibilité. L'asymétrie d'information place le niveau de la taxe au-dessous du niveau Pigouvien ajusté selon l'exercice du pouvoir du marché. En cas de sélection par le critère d'invincibilité la taxe peut basculer un équilibre séparateur dans un équilibre mélangeant ce qui rétablit le problème d'asymétrie d'information. Enfin, on montre que le choix de qualité environnementale de la part de l'entreprise est sous-optimale même si elle internalise le dommage environnemental.

Three problems in the market of a green product: fiscal avoidance, signal and vertical differentiation

Abstract: Environmental quality having features of a public good is the subject of the thesis. In a theoretical framework, we study a means of environmental regulation of a polluting firm endowed with market power and then determine the optimal decentralized choice of environmental quality. We start with examining how tax avoidance affects the optimal second-best tax on polluting emissions in a monopoly setting. The firm is owned by shareholders who differ in their cost of tax dodging. The optimal tax should correct two negative externalities of avoidance: the firm's free-riding effect and a tax base erosion effect. This free-riding makes the regulator either impotent or unfair, depending on the severity of the environmental damage and the firm's efficiency. Next, we analyze the impact of an environmental tax on the signaling price strategy of a monopoly that communicates to consumers the unobservable information about firm's high environmental performance. We use the intuitive and undefeated criteria of equilibrium selection. Asymmetric information places the optimal second-best tax below the level required under complete information. In the case of undefeated equilibria selection, the tax may induce a 'migration' from separating equilibrium to pooling making the firm prefer to conceal the private information about environmental quality. Finally, we show that market choice of environmental quality by a firm that internalizes environmental damage from polluting emissions is yet suboptimal.

Discipline : Sciences Economiques (Section 5)

Mots-Clés : qualité environnementale, régulation, pouvoir du marché, évitement fiscal, information incomplète, choix de la qualité

Keywords: environmental quality, regulation, market power, fiscal avoidance, incomplete information, quality choice

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