Harnessing Market Forces to Regulate Pollution

Oliwia Kurtyka,

LERNA, Toulouse School of Economics,

Manufacture des Tabacs, 21 allee de Brienne, 31000 Toulouse - FRANCE,

tel: +33 (0)5-61-12-88-17, Email: okurty@gmail.com

Philippe Mahenc (corresponding author)

LERNA, Toulouse School of Economics,

Manufacture des Tabacs, 21 allee de Brienne, 31000 Toulouse - FRANCE,

Email: mahenc@univ-perp.fr

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Abstract

This paper analyses the regulation of pollution in a market where Bertrand competitors supply two differentiated varieties of a good: a conventional-polluting variety and a green variety. Ramsey pricing and optimal taxation of the conventional variety are successively examined. The two types of regulation are equivalent and achieve the optimal allocation of the two varieties by harnessing Bertrand competition. Taxing (subsidizing) the conventional variety softens (strengthens) price competition and boosts (discourages) the demand for the green variety. Taxes set above the marginal damage induce the polluter to internalize both the environmental externality and the social cost of Bertrand competition.

Keywords: Bertrand competition, Differentiated products, Environmental taxation, Green product, Ramsey price.

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1 Introduction

Thanks to Buchanan (1969), the idea is now well understood that the tax intended to internalize the environmental externality generated by a monopolist's activity has the undesirable effect of even more reducing the monopolist's suboptimal output. Consequently, such a tax cannot be optimally set equal to the environmental damage, as required by the Pigovian principle in a competitive industry. The dual task of regulating pollution and correcting for the monopolist's tendency to underproduce usually leads the regulator to set the tax below the marginal damage from pollution (see Lee (1975) and Barnett (1980)). A similar conclusion has been derived, more recently, in the standard context of a Cournot oligopoly (see Katsoulacos and Xepapadeas (1995) and Simpson (1995), or Requate (2005) for a detailed survey), reinforcing the idea that a sound environmental regulation constrained by imperfectly competitive markets should be laxer than under perfect competition.

However, there may be some concern with this idea if the polluting good sold under market power is challenged by a more environmentally friendly substitute. Then, scaling down the tax on the polluting good to encourage its production is likely to divert buyers from purchasing the green good, which does not sound desirable for the environment. If, moreover, the green competitor also enjoys some market power and restricts too much output accordingly, then it may be socially efficient to boost the demand for the green good more than that for the polluting good, thereby raising, instead of reducing, the tax on the polluting good. Furthermore, the "induced" effects of taxation emphasized by Myles (1987 and 1989) for imperfectly competitive markets are still present when one competitor is a polluter. Any change in the tax levied on his output not only raises the cost of producing the polluting good, but also affects the equilibrium prices of the differentiated goods, which in turn, influences business switching between goods.

This paper addresses these intricate issues by investigating Bertrand competition between a regulated producer and his unregulated rival. The regulated producer supplies the conventional variety of a good, that pollutes the environment, and the unregulated producer supplies the green variety of the same good. Our goal is to show how the regulator can harness the forces of Bertrand competition through taxes or subsidies, in order to achieve the optimal allocation of the two varieties among buyers. In the market left to itself, the price signals resulting from Bertrand competition are misleading because they reflect the producers' incentives to steal the other's business, which do not necessarily lead to a benefit to society. By influencing the price competition, the regulator is able to foster business switching between varieties in a socially efficient way. One surprising feature of regulation in a regime of Bertrand competition with differentiated varieties is that a tax or a subsidy applied to one variety respectively softens or increases the intensity of price competition. Thus, taxing the conventional variety to curb polluting emissions induces both competitors to behave less aggressively in the pricing game. This is likely to entail large social costs, which must be ultimately internalized in the decision making of the polluting producer.

Throughout the paper, we analyze two types of regulation which prove equivalent. First, we determine the optimal Ramsey price for the polluting variety according to the partial equilibrium viewpoint adopted by Laffont and Tirole (1993), and second, we establish the linkage with the traditional environmental approach developed, among others, by Sandmo (1975), Lee (1975) and Barnett (1980), by investigating the optimal taxation of the conventional variety.

Our theoretical model combines horizontal differentiation with the recent approach in environmental literature that considers environmental friendliness as a quality attribute of a product (see Arora and Gangopadhyay ((1995), Cremer and Thisse (1999), Bansal and Gangopadhyay (2003))[1]. The classic model of Hotelling (1929) is modified to capture the two following ideas: besides differing by their design, varieties are also differentiated by

[1]A somewhat different view is proposed by Eriksson (2004) who investigates a model in which environmental quality is partly a horizontal characteristic of the product.

their impact on the environment; and second, buyers have the same aversion to pollution but heterogeneous tastes for the design. This formalization yields that more aversion to pollution makes the neighboring clienteles, at the same time, less captive of the polluting producer and more captive of the green producer.

The paper is partly motivated by the system of subsidies and taxes, called "bonus-malus", which has recently been implemented in the French automobile industry. These fiscal measures are intended to both encourage the purchase of low-emission vehicles and discourage the purchase of high-emission vehicles. To some extent, such a policy is reminiscent of the "gas guzzler" tax on new cars established by the United States Energy Tax Act of 1978 (see Stavins (2000)). According to the French environment ministry, the "bonus-malus" system has switched 40% of the market toward more environmentally friendly vehicles, but it was blamed by the finance ministry for increasing the cost of public funds. The automobile industry is clearly not perfectly competitive as shown by the empirical works of Berry et al. (1995) and Goldberg (1995). This is the reason why our framework grounds on a variant of the Bertrand differentiated products model. Moreover, car manufacturers now compete in varieties that differ not only in terms of their horizontal attributes such as design, style or convenience, but also in their environmental attributes. Clearly, the model might also fit any industry in which a conventional and a green variety are substitutes, such as high-carbon fuel vs. green energy, or road freight vs. railway.

We start the analysis by examining how the allocation of varieties created by unbridled Bertrand competition deviates from the social optimum. It turns out that the polluting producer is guilty or not of stealing the other's clientele, depending on the severity of the environmental damage and the comparison between buyers' aversion to pollution and the marginal savings from producing the conventional variety.

The analysis of pricing by the regulated producer of the conventional variety emphasizes a deviation of the Lerner index from the standard Ramsey price which only reflects the revenue-raising requirement. This deviation is explained by the necessity for the regulated firm to internalize both the damage from pollution and the effect of the regulated price on the pricing behavior of the green competitor. The modification required to incorporate imperfect competition into the standard Ramsey tax rule is similar to that previously identified by Myles (1989) in a general equilibrium context. Moreover, the term that adjusts for correcting the environmental externality is consistent with Pigou's (1920) idea to confront the generator of an externality with a price reflecting the damage inflicted on others.

Implementation of the optimal allocation of varieties can also be achieved by more traditional instruments such as taxes or subsidies. The amount by which the optimal policy deviates from the standard Pigovian tax depends on which producer is stealing the other's business in the market left to itself, as well as the magnitude of the allocative distortions created by unbridled Bertrand competition. Taxes foster business switching towards the green variety by softening Bertrand competition. In some circumstances, they are optimally set above the marginal damage to induce the polluting producer to internalize the social cost of Bertrand competition, in addition to the environmental externality. Conversely, subsidies to the conventional variety divert buyers from the green variety by increasing the intensity of price competition. They are shown to emerge only if the marginal damage from pollution at the social optimum falls sufficiently short of the marginal social value of the conventional variety.

The paper of Lange and Requate (1999) is closely related to the present analysis in that it investigates optimal taxation in a price-setting duopoly with differentiated commodities. The authors first determine the dual instrument of second-best differentiated taxes. As a result, both taxes have a structure similar to that derived for the Lee-Barnet tax. Then, Lange and Requate derive the formula for uniform taxation and illustrate, with a numerical example, the result that the optimal tax may exceed marginal damage for the reason of "offsetting the extreme advantage (of the polluter) with respect to the private cost". Our analysis shows that this intuition is not always correct. When the polluter has much lower production costs than his green rival, the marginal savings from producing the conventional variety are high, which makes buyers set a great value to this variety. This provides the regulator an incentive to reduce the tax on the conventional variety, and even subsidize it in order to divert buyers from the green variety. From our results, the tax evaluated at the shadow price of public funds must be set above the marginal damage in one peculiar state of the economy, where the marginal social value of the conventional variety evaluated at the shadow price of public funds is less than the marginal damage from pollution. There may be two reasons for this: first, the marginal savings from producing the conventional variety are lower than the buyers' aversion to pollution, and second, the damage from pollution is severe at the social optimum. In these circumstances, taxes exceed the marginal damage to ensure that all the costs imposed on society, due to pollution and Bertrand competition, are internalized into the polluting producer's decision making. The severity of the environmental damage already calls for high taxes. As taxing the polluting variety softens price competition between the differentiated varieties, a welfare loss is inflicted on society that must be offset by rising further taxes.

The paper is organized as follows. Section 2 presents the model and investigates Bertrand competition in the unregulated market. Section 3 analyzes the regulation of pollution and prices by examining successively Ramsey pricing and optimal taxation of the conventional variety. Section 4 offers conclusions and proposes some extensions of the model.

2 The model

Consider the following variation of Hotelling's (1929) model in which buyers are uniformly distributed along a segment of unit length.

Two differentiated varieties of a same product are supplied by Bertand competitors located at the extremes of the segment. The two varieties are differentiated along two characteristics, namely an horizontal characteristic such as the design of the product, and the environmental damage which will be treated here as a vertical characteristic. Variety 1 located at the left extreme of the segment is a conventional variety of the product that generates polluting externalities. Variety 2 located at the right extreme is the "green" substitute of the product, so called because it has no impact on the environment[2]. Variety i is sold at price p_i by producer i who incurs a constant marginal cost of production c_i. The conventional-polluting variety of the product is assumed to be less costly to produce than the green variety, that is, $c_1 < c_2$. As far as the automobile industry is concerned, this captures the idea that high-emission vehicles are less expensive than low-emission vehicles whose production requires more R&D expenditures[3].

[2]In the terminology of Kotchen (2006), both varieties can be seen as impure public goods, in the sense that they generate private consumption and a public good – environmental quality – as a joint product.

[3]Another illustration may be energy, with coal or gas for the conventional variety, and renewable energy for the green variety, such as sun, wind or water. Presently, the most competitive renewable energy with a wide applicability is wind power, which is still more expensive than power from coal and gas-fired combined cycle (see Lomborg (2001) p. 131).

Let X denote the output of the polluting producer. The damage from pollution generated by the conventional variety will be given by function $D(X)$ with $D'(X)$ and $D''(X) > 0$, where primes denote derivatives.

Both varieties provide buyers with the same gross surplus of value v. Buyers preferences vary along two dimensions. First, the location $x \in [0, 1]$ of a buyer represents his taste for the product, that is, the buyer's ideal variety. When purchasing one variety, buyers pay the same fitting cost $t \geq 0$ per unit of distance, which represents the utility loss for not purchasing the ideal product[4]. Second, all buyers are assumed to prefer the product to be more environmentally friendly. This will be captured by an index of environmental concern $\beta > 0$ measuring the buyers' utility loss when purchasing the conventional variety, due to a common aversion to pollution.

There may be two different interpretations of what is called "environmental concern" here. First, buyers experience the same troubles from purchasing the conventional variety, caused for instance by risks to health or in nutritional effects[5]. Another interpretation is that buyers feel some guilt when purchasing the conventional variety, because it contributes to the degradation of the natural environment. This guilt complex is closely related to what Andreoni (1995) calls "cold prickle", that is, the negative counterpart of the

[4]If the product is energy, both the conventional and the green varieties need to be adapted to the good they complement, in which case t stands for the technological cost of fitting the purchased variety and its complementary good together.

[5]Conrad (2005) provides several other examples relating to such troubles.

warm glow buyers may experience from doing their part to protect the environment by purchasing the green variety. If buyers represent downstream firms rather than final consumers, then the disutility can be related to corporate social responsibility and the loss of social reputation.

Buyers are assumed to purchase at most one unit of variety. It is also assumed that v is large enough for all buyers to find a variety for which their surplus is positive in equilibrium. A buyer located at $x \in [0,1]$ derives a surplus $v - \beta - p_1 - tx$ from purchasing variety 1 at price p_1, and $v - p_2 - t(1-x)$ from purchasing variety 2 at price p_2. The polluting producer's market share X corresponds to the marginal buyer who is indifferent between both varieties. Thus, X solves equation:

$$v - \beta - p_1 - tX = v - p_2 - t(1-X). \tag{1}$$

It follows that the demand functions for the conventional variety and the green variety are respectively given by:

$$X_1(\mathbf{p}) \equiv \frac{1}{2} + \frac{p_2 - p_1 - \beta}{2t}, \tag{2}$$
$$X_2(\mathbf{p}) \equiv \frac{1}{2} + \frac{p_1 - p_2 + \beta}{2t}, \tag{3}$$

where $\mathbf{p} \equiv (p_1, p_2)$ is the vector of prices. From (2) and (3), it can be seen that buyers' environmental concern both reduces the demand for the conventional variety and enhances the demand for the green variety.

Let $\varepsilon_1(\mathbf{p}) \equiv -\frac{\partial X_1(\mathbf{p})}{\partial p_1}\frac{p_1}{X_1}$ and $\varepsilon_2(\mathbf{p}) \equiv -\frac{\partial X_2(\mathbf{p})}{\partial p_2}\frac{p_2}{X_2}$ denote the price elasticities of demands for the conventional variety and the green variety, respectively. These elasticities can be expressed here as

$$\varepsilon_1(\mathbf{p}) = \frac{p_1}{t-\beta+p_2-p_1} \text{ and} \tag{4}$$

$$\varepsilon_2(\mathbf{p}) = \frac{p_2}{t+\beta+p_1-p_2}. \tag{5}$$

Interestingly enough, the demand elasticities for the conventional and the green varieties are respectively increasing and decreasing with β. This captures the idea that a higher aversion to pollution makes the neighboring clienteles, at the same time, less captive of the conventional producer and more captive of the green producer. Hence, the greater the degree of vertical product differentiation associated with a higher value of β, the greater the market power of the green producer, but the lower the market power of the conventional producer. By contrast, demands for both varieties are less elastic when buyers are more fussy about the variety design, hence the degree of market power is greater for both producers with a higher degree of horizontal product differentiation.

2.1 Socially optimal allocation of varieties

As a benchmark, we derive the socially optimal allocation of varieties among buyers. Social welfare is represented by the sum of buyers' surplus and firms profits less the sum of the social costs entailed by the environmental damage and buyers' imperfect fit in terms of design. The welfare function is

$$W(X) = v - \beta X - c_1 X - c_2 (1 - X) - D(X) - T(X), \tag{6}$$

where $T(X)$ is the buyer's average fitting cost[6]. Thus, from the social standpoint, the market should be split at the location X^* that solves equation[7]

$$c_2 - c_1 - \beta = T'(X^*) + D'(X^*). \tag{7}$$

The left-hand side of (7) reflects the marginal savings in production costs of one buyer purchasing the conventional variety, net of his aversion to pollution. It is positive either when the green variety is far more costly to produce than the conventional variety, or when buyers have a low aversion to pollution. Conversely, buyers' concern for the environment may be so high that the utility loss from buying the polluting variety exceeds the marginal

[6] Total fitting cost is equal to: $T(X) = \int_0^X tsds + \int_X^1 t(1-s)ds = t\frac{X^2+(1-X)^2}{2}$ with marginal cost $T'(X) = 2t(X - \frac{1}{2})$.

[7] It can be checked that the strict convexity of $D(X)$ ensures that second-order conditions are satisfied.

savings in production costs, that is, $c_2 - c_1 < \beta$. The right-hand side of (7) is the sum of the marginal cost of fitting with the conventional variety and the marginal damage from pollution. The efficient allocation of varieties requires that the marginal social value of the polluting variety must exactly offset the sum of the marginal social costs entailed by pollution and imperfect fit. As $T'(X) = 2t(X - \frac{1}{2})$, the function $T(X)$ is minimized at the market center: buyers' fit with the conventional variety entails a marginal cost only if $X > \frac{1}{2}$, otherwise $T'(X)$ reflects marginal savings on this imperfect fit. Note that social efficiency requires to split the market at $X^* < \frac{1}{2}$ as long as $c_2 - c_1 - \beta < 0$. From (7), we can derive the socially optimal volume of sales for the polluting producer:

$$X^* = \frac{1}{2} + \frac{c_2 - c_1 - \beta - D'(X^*)}{2t}. \tag{8}$$

When $c_2 - c_1 - \beta < D'(X^*)$, that is, the marginal damage from pollution exceeds the marginal social value of the polluting variety, the market share of the polluting producer should be lower than that of the new firm from a social standpoint.

Let us build the model on the assumption that providing both varieties on the market is socially efficient. Supplying the conventional variety is socially efficient provided that the polluting producer would not be driven out of the market if both varieties were sold at marginal cost, i.e., $X^* > 0$. For the same reason concerning the green variety, we must have $X^* < 1$. Hence, we will assume throughout the article that t is sufficiently high to satisfy the following twofold inequality:

$$c_2 - c_1 - \beta - t < D'(X^*) < c_2 - c_1 - \beta + t. \tag{9}$$

Lemma 1: *Under the assumption* (9)*, it is socially efficient to split the market at* $X^* = \frac{1}{2} + \frac{c_2 - c_1 - \beta - D'(X^*)}{2t}$.

2.2 The unregulated market

We begin our analysis by investigating the Bertrand equilibrium outcome when the market is not regulated. The profit earned from variety i is $(p_i - c_i)X_i(\mathbf{p})$ and the first-order conditions are given by:

$$(p_i - c_i)\frac{\partial X_i(\mathbf{p})}{\partial p_i} + X_i(\mathbf{p}) = 0, i = 1, 2. \tag{10}$$

One can easily check that second-order conditions are satisfied. As is usual with imperfect competition, the profit-maximizing behavior induces producers to exploit their power over price and maintain a profit margin above marginal cost. Moreover, Bertrand competition provides producers with a private incentive to steal the rival's clientele, thereby restricting the competitor's output more than is socially desirable. The resulting allocation of varieties among buyers at Bertrand equilibrium is biased away from the social optimum, as will be shown below. This inefficiency has the same flavor as that generated by the business-stealing effect (see Mankiw and Whinston (1986)) when a firm enters an imperfectly competitive market[8]. First-order conditions can be rewritten in the usual way showing that the Lerner index is equal to the inverse of the price elasticity of demand:

$$\frac{p_i - c_i}{p_i} = \frac{1}{\varepsilon_i\left(\mathbf{p}\right)}, i = 1, 2. \tag{11}$$

Conditions (11) tell that market power is a decreasing function of the price elasticity of demand. These conditions yield two reaction functions, which can be solved for the pair $\mathbf{p}^B \equiv \left(p_1^B, p_2^B\right)$ of Bertrand-Nash equilibrium prices:

$$p_1^B = \frac{c_2 + 2c_1 - \beta + 3t}{3}, \tag{12}$$

$$p_2^B = \frac{c_1 + 2c_2 + \beta + 3t}{3}. \tag{13}$$

The expressions above clearly show that β and t have contrasting effects on Bertrand equilibrium prices. An increase in buyers' aversion to pollution both lowers the price of the conventional variety and raises the price of the

[8]The business stealing effect is generally related to entry issues. When a new firm enters the market, it brings new output that increases the welfare. However, existing firms decrease their output in response to the entry. Therefore, the final impact on welfare depends on whether the additional output is higher than the one "stolen" from existing firms.

green variety, while an increase in buyers' cost of fitting in terms of design raises prices for both varieties. As previously shown, a rise in environmental concern increases the green producers' market power by decreasing the price elasticity of demand for the green variety. This allows the green producer to charge a higher price for his variety. Furthermore, producers compete less strenuously when buyers have more aversion to design: the more differentiated varieties are along the horizontal characteristic, the higher the equilibrium prices.

Substituting the prices given by (12) and (13) into (2) and (3) yields the following demands for, respectively, the conventional and the green varieties:

$$X_1(\mathbf{p}^B) = \frac{1}{2} + \frac{c_2 - c_1 - \beta}{6t}, \tag{14}$$

$$X_2(\mathbf{p}^B) = \frac{1}{2} + \frac{c_1 - c_2 + \beta}{6t}. \tag{15}$$

To bypass exit problems, it will be assumed that t is high enough to guarantee $0 < X_1(\mathbf{p}^B) < 1$[9]. The expressions above show that, *ceteris paribus*, a higher aversion to pollution increases the market share accruing to the green producer in equilibrium, while it reduces that of the polluting producer. The equilibrium profits for the conventional and the green varieties are respectively given by:

[9] This is equivalent to $-3t < c_2 - c_1 - \beta < 3t$.

$$\Pi_1^B = \frac{(c_2 - c_1 + 3t - \beta)^2}{18t}, \tag{16}$$

$$\Pi_2 = \frac{(c_1 - c_2 + 3t + \beta)^2}{18t}. \tag{17}$$

From the expressions above, it turns out that changes in β or t do not have the same effect on the Bertrand equilibrium. An increase in buyers' aversion to pollution raises (lowers) both the price and the volume of sales for the green variety in the Bertrand equilibrium, thereby augmenting (reducing) the green (conventional) producer's profit. Thus, the green producer is the only one to benefit from an increase in vertical differentiation: business is switching towards the green variety which can be sold at a higher price due to higher market power. By contrast, an increase in horizontal differentiation is beneficial to both producers. From (16) and (17), when buyers incur a higher cost of fitting with the design of the product, profit raises for the green variety as well as for the conventional variety. The reason why can be found in (12) and (13): an increase in horizontal differentiation softens price competition between varieties. The following lemma summarizes this result.

Lemma 2: *A rise in aversion to pollution augments the equilibrium profit of the green producer and reduces that of the conventional producer, whereas an increase in fitting cost raises the equilibrium profit for both producers.*

Clearly, Bertrand competition is a major source of allocative distortions in the market of differentiated varieties. One standard way to evaluate the magnitude of these distortions is to resort to Lerner indexes. From the equations (11), $\frac{p_2^B}{\varepsilon_2(\mathbf{p}^B)} - \frac{p_1^B}{\varepsilon_1(\mathbf{p}^B)}$ reflects the difference in profit margin between the two varieties. Hence, it provides a measure of the efficiency loss attributable to the exercise of market power by producers. Easy calculations yield

$$\frac{p_2^B}{\varepsilon_2(\mathbf{p}^B)} - \frac{p_1^B}{\varepsilon_1(\mathbf{p}^B)} = -\frac{2}{3}\left(c_2 - c_1 - \beta\right). \tag{18}$$

Consider that $c_2 - c_1 - \beta > 0$, that is, the marginal social value of the polluting variety is positive for buyers. From equation (18), the polluting producer's profit margin is higher than that of his green competitor. Moreover, the expression of demand (14) shows that, in this case, the polluting producer also obtains a greater market share than does the green producer. Thus, the market left to itself under Bertrand competition favors the conventional variety. Conversely, when $c_2 - c_1 - \beta < 0$, Bertrand competition is acting on behalf of the green producer.

Lemma 3: *If* $c_2 - c_1 - \beta > (<)\, 0$*, then Bertrand competition gives the polluting producer a higher (lower) market share as well as a higher (lower) profit margin than has the green producer.*

From the social standpoint, one expects the price signals resulting from Bertrand competition to be misleading: the market prices by themselves fail to allocate efficiently the two varieties, that is, $X_1(\mathbf{p}^B)$ is distorted away from X^*. The key point is that Bertrand competition between differentiated varieties implies transfers between competitors that do not correspond to a benefit to society. One producer is always "stealing" the other's clientele in Bertrand equilibrium, since the resulting market split never coincides with the socially optimal one. One measure of this business stealing is given by

$$X_1(\mathbf{p}^B) - X^* = \frac{3D'(X^*) - 2(c_2 - c_1 - \beta)}{6t}. \tag{19}$$

Proposition 1:

In the absence of regulation, if $c_2 - c_1 - \beta > 0$, *then:*

- *the polluting producer steals the green producer's clientele, and so pollutes too much, when* $D'(X^*) > \frac{2}{3}(c_2 - c_1 - \beta)$,
- *the green producer steals the polluting producer's clientele when* $D'(X^*) < \frac{2}{3}(c_2 - c_1 - \beta)$.

If $c_2 - c_1 - \beta < 0$, *then the polluting producer steals the green producer's clientele and pollutes too much.*

Proposition 1 enlightens the various directions of the allocative distortion due to Bertrand competition. It turns out that the polluting producer may steal the green producer's clientele essentially for two reasons: first, he never pays for the polluting damage created by the conventional variety, and second, he captures buyers who value more the green variety than the conventional one. However, it may also happen that the green producer steals the polluting producer's clientele.

More precisely, when $c_2 - c_1 > \beta$, the marginal savings from producing the conventional variety dominates buyers' aversion to pollution, hence the marginal social value of the polluting variety is positive for buyers. Nevertheless, the polluting producer's behavior restricts too much the sales of the green variety when $D'(X^*) > \frac{2}{3}(c_2 - c_1 - \beta)$. Otherwise, when $D'(X^*) < \frac{2}{3}(c_2 - c_1 - \beta)$, there is too much green variety on the market because pollution is not so worrisome at the social optimum and buyers set a lower value to the green variety than to the conventional one.

On the contrary, when $c_2 - c_1 < \beta$, buyers value more the green variety than the conventional one. Moreover, inequality $c_2 - c_1 - \beta < D'(X^*)$ is satisfied. By (8), the polluting producer should have a lower market share than has the green producer from a social standpoint. As stated in lemma 3, Bertrand competition goes in the right direction since the polluting producer obtains, in equilibrium, a lower market share than that of his rival. Nevertheless, there is still overprovision of the conventional variety because the polluting polluter does not take into consideration the environmental externality he imposes on society.

3 Regulation of the polluting producer

Let us now examine the regulator's problem. Beside the problem of pollution, there are two other sources of potential market failure here, due to excessive market power and imperfect fit between buyers' tastes and the design of varieties. Thus, in addition to his environmental goal, the regulator will also face the dual task of correcting for the distortions associated with Bertrand competition and imperfect fit. As will be shown, the regulator is able to mobilize and harness the market forces on behalf of the environment. In what follows, we will first adopt the regulatory approach *à la* Ramsey widely investigated by Laffont and Tirole (1993), and next relate it with the traditional environmental policy investigated by Lee (1975), Sandmo (1975) and Barnett (1980).

3.1 Optimal pricing of the conventional variety

The polluting producer is regulated and competes with the unregulated green producer who then equates marginal revenue and marginal cost in accordance with (10). Pricing decisions are assumed to be simultaneous, meaning that the regulator has no commitment power.

Following Laffont and Tirole (1993), the regulator pays directly the cost of producing the conventional variety and receives the revenue from sales so that he must raise $(c_1 - p_1)\, X_1(\mathbf{p})$ through distortionary taxation. It will be assumed that a marginal dollar of the regulated producer's profit has a social value $1+\lambda$ that is more than a dollar. The idea is that any dollar in the regulated producer's revenue reduces the cost of regulation by one dollar and thus reduces the deadweight loss of distortionary taxation by $1+\lambda$ dollars. By contrast, none of the green producer's profit is redistributed to the regulator. Thus, the social welfare is

$$W(\mathbf{p}) = v - \beta X_1(\mathbf{p}) - p_1 X_1(\mathbf{p}) - c_2 X_2(\mathbf{p}) - D(X_1(\mathbf{p})) - T(X_1(\mathbf{p})) + (1+\lambda)(p_1 - c_1) X_1(\mathbf{p}), \tag{20}$$

Given the profit-maximizing behavior of the green producer, the regulated producer maximizes $W(\mathbf{p})$ with respect to p_1. Denote by $\mathbf{p}^* \equiv \left(p_1^R, p_2^U\right)$ the pair of equilibrium prices resulting from Bertrand competition, where p_1^R is the optimal price charged by the regulated producer and p_2^U is the profit-maximizing price charged by the unregulated producer. Given parameter values ensuring $0 < X_1(\mathbf{p}^*) < 1$ (see the appendix), the optimal price for the conventional variety must satisfy the following first-order condition

$$(c_2 - \beta - p_1 - D'(X_1(\mathbf{p}^*)) - T'(X_1(\mathbf{p}^*)) + (1+\lambda)(p_1 - c_1)) \frac{\partial X_1(\mathbf{p}^*)}{\partial p_1} - X_1(\mathbf{p}^*) + (1+\lambda) X_1(\mathbf{p}^*) = 0. \tag{21}$$

which can be rewritten

$$(c_2-\beta-(1+\lambda)\,c_1)\frac{\partial X_1(\mathbf{p}^*)}{\partial p_1}+\lambda p_1\frac{\partial X_1(\mathbf{p}^*)}{\partial p_1}+\lambda X_1(\mathbf{p}^*) = (D'(X_1(\mathbf{p}^*)) + T'(X_1(\mathbf{p}^*)))\,\frac{\partial X_1(\mathbf{p}^*)}{\partial p_1}, \tag{22}$$

where:

- $(c_2 - \beta - (1+\lambda)\,c_1)\frac{\partial X_1(\mathbf{p}^*)}{\partial p_1}$ is the marginal social value of the conventional variety for buyers stemming from the savings in production costs and buyers' aversion to pollution (note that, now, the cost of producing the conventional variety is evaluated at the shadow price of public funds),

- $\lambda p_1\frac{\partial X_1(\mathbf{p}^*)}{\partial p_1} + \lambda X_1(\mathbf{p}^*)$ is the marginal revue of supplying the conventional variety, computed at the shadow price of public funds,

- $(D'(X_1(\mathbf{p}^*)) + T'(X_1(\mathbf{p}^*)))\,\frac{\partial X_1(\mathbf{p}^*)}{\partial p_1}$ is the sum of the marginal social costs entailed by pollution and imperfect fit.

Hence, the optimal price of the conventional variety p_1^R is given by the equality between its social marginal cost and the sum of its marginal social value and the marginal revenue obtained from sales.

One interesting property of the model derived from (2) is that, for all $\mathbf{p}$, we have

$$p_2 - p_1 - \beta = T'(X_1(\mathbf{p})). \tag{23}$$

Thus, Bertrand competition between the regulated producer and his unregulated competitor has the socially beneficial effect of correcting for the distortion due to buyers' imperfect fit. Using property (23) to replace $T'(X_1(\mathbf{p}^*)$ by $p_2^U - p_1^R - \beta$ in (22), it is straightforward to check that the local second-order condition for welfare maximization is satisfied. Moreover, the price elasticity of demand for the green variety satisfying (11)can be introduced into (22) to state the modified version of the Ramsey formula given by the following proposition.

Proposition 2: *The optimal Lerner index for the conventional variety is given by*

$$\frac{p_1^R - c_1}{p_1^R} = \frac{\lambda}{(1+\lambda)} \frac{1}{\varepsilon_1(\mathbf{p}^*)} + \frac{1}{(1+\lambda)\, p_1^R}(D'(X_1(\mathbf{p}^*)) + \frac{p_2^U}{\varepsilon_2(\mathbf{p}^*)}). \tag{24}$$

The first term in the right-hand side of (24) is the standard Ramsey price which measures the social contribution of the revenue earned from the conventional variety. As usual, this price states that it is optimal to charge a higher price for varieties with a low price elasticity than for varieties with a high price elasticity. In the case where environmental externalities are absent and the green producer is a price-taker (i. e., $D'(X_1(\mathbf{p}^*)) = 0$ and $p_2^U = c_2$), the optimal Lerner index would simply be the Ramsey price. However, with environmental externalities and a differentiated variety sold under market power, the Lerner index deviates from the Ramsey price. The reason is that the social value of output of the regulated producer must reflect not only the marginal social value of the conventional variety for buyers, but also the effects on two further distortions: first, the distortion due to the environmental externality, and second, the distortion associated with Bertrand competition. Internalization of the damage from pollution corresponds to the second term in the right-hand side of (24), while internalization of the effect of the regulated price on the pricing behavior of the green competitor is captured by the third term in the right-hand side of (24). The latter term is closely related to the imperfect competition "correction" term which has been shown by Myles (1989) to modify the Ramsey tax rule for markets with imperfect competition. As a result here, the optimal Lerner index is a weighted average of a revenue-raising Ramsey term and the marginal social cost due both to the environmental damage and the distortion associated with the exercise of market power by the green producer. When raising revenue is not distortionary, λ is equal to zero and the Ramsey term is zero. Then, the optimal Lerner index tends to the marginal social cost associated with the environmental damage and the green producer's market power, which should nevertheless be internalized by the regulated producer. When the shadow costs of public funds become very large, the Ramsey term tends to the monopoly price for the conventional variety.

Direct regulation of the polluting producer implied by Ramsey pricing may not be feasible due to some political reluctancy or administrative constraints. Nevertheless, the Ramsey approach of regulation is somehow tantamount to examining here the alternative between a tax or a subsidy, which are more traditional instruments of regulation in the environmental literature. The next section demonstrates that the two types of regulation are indeed equivalent.

3.2 Optimal taxation of the conventional variety

Let us now consider that the regulator must resort to taxes or subsidies in order to allocate varieties among buyers. The regulator must choose a tax τ^* on each unit of the conventional variety, which will take negative values if it turns out to be a subsidy. Let $\mathbf{p}^B(\tau^*) \equiv \left(p_1^B(\tau^*), p_2^B(\tau^*)\right)$ denote the pair of equilibrium prices resulting from Bertrand competition between the taxed variety and the untaxed one. Then, the profit earned from the conventional variety is $(p_1^B(\tau^*) - c_1 - \tau^*)X_1(\mathbf{p}^B(\tau^*))$ and $p_1^B(\tau^*)$ must solve the first-order condition for profit maximization of the polluting producer:

$$(p_1^B(\tau^*) - c_1 - \tau^*)\frac{\partial X_1(\mathbf{p}^B(\tau^*))}{\partial p_1} + X_1(\mathbf{p}^B(\tau^*)) = 0. \qquad (25)$$

Note that substituting $c_1 + \tau^*$ to c_1 in the expressions of p_1^B and p_2^B given by (12) and (13) yields

$$p_1^B(\tau^*) = \frac{c_2 + 2c_1 - \beta + 3t + 2\tau^*}{3}, \tag{26}$$

$$p_2^B(\tau^*) = \frac{c_1 + 2c_2 + \beta + 3t + \tau^*}{3}. \tag{27}$$

From the expressions above, a tax softens price competition, while a subsidy increases the intensity of price competition. As taxes raise the costs incurred by the polluting producer, they both lower his profit and increase the profit of his green competitor (see (16) and (17)). In this regard, taxes make the polluting producer soft, whereas subsidies make him tough. Thus, the choice between a tax or a subsidy depends here on whether or not the regulator is willing to strengthen the green producer. Moreover, using (11), equation (25) can be rewritten to express the Lerner index

$$\frac{p_1^B(\tau^*) - c_1}{p_1^B(\tau^*)} = \frac{\tau^*}{p_1^B(\tau^*)} + \frac{1}{\varepsilon_1(p_1^B(\tau^*), p_2^B(\tau^*))}. \tag{28}$$

As τ^* is aimed at implementing the optimal allocation of varieties, we must have that, first, $p_1^B(\tau^*) = p_1^R, p_2^B(\tau^*) = p_2^U$, and second, the Lerner index given by (24) is equal to that given by (28). It follows that the optimal tax is the sum of a Ramsey term and externality-correcting terms, which is closely related to the formula derived by Sandmo (1975).

Proposition 3: *Implementation of the optimal allocation of varieties* *among buyers is achieved by τ^* such that*

$$(1+\lambda)\,\tau^* = D'(X_1(\mathbf{p}^*) - \frac{p_1^R}{\varepsilon_1(\mathbf{p}^*)} + \frac{p_2^U}{\varepsilon_2(\mathbf{p}^*)} \tag{29}$$

In Sandmo (1975), the optimal tax is a weighted average of the marginal damage and an efficiency term which reflects the regulator revenue requirement. The formula given by (29) departs from that in Sandmo (1975) in that the regulator employs here the tax not only to satisfy his revenue requirement, but also to simultaneously correct for two negative externalities: first, the pollution externality, and second, the externality exerted on the green producer through Bertrand competition. One interpretation of (29) is that the tax evaluated at the shadow price of public funds, i. e., $(1+\lambda)\,\tau^*$, achieves an optimal trade-off between the two distortions due respectively to the environmental damage and Bertrand competition with differentiated varieties. When the shadow costs of public funds become small ($\lambda = 0$) and the green variety is supplied by a price-taker ($\varepsilon_2(\mathbf{p}^*)$ becomes very large), the optimal tax reduces to the two terms identified by Lee (1975) and Barnett (1980): they reflect the conflict between the welfare gain from internalizing the marginal damage from pollution and the inefficiency stemming from the market power of the polluting producer. In such a case, setting the tax at the Pigovian level, which fully internalizes the marginal damage from pollution under perfect competition, would ignore the welfare loss of rising further the price of the conventional variety, which is already overpriced by the exercise of market power by the polluting producer. The main difference with this traditional approach is that the regulator here cannot ignore the presence of a green variety sold under market power. In a regime of Bertrand competition between the regulated and the unregulated sectors, the regulator harnesses the force of competition to generate a socially beneficial business switching. The regulator must take into consideration that the green producer will react to any price increase (decrease) of the taxed variety by raising (lowering) the price of the green variety, owing to the strategic complementarity of prices which characterizes Bertrand competition with differentiated varieties. Hence, regulation can make the polluting producer more or less tough in the pricing game. The third term in the right-hand side of (29) captures the effect on social welfare of the green producer's strategic pricing. Intuitively, the intent of the regulator is to make the taxed producer internalize the external cost imposed on the green producer. A positive difference in profit margins, that is, $\frac{p_2^U}{\varepsilon_2(\mathbf{p}^*)} - \frac{p_1^R}{\varepsilon_1(\mathbf{p}^*)} > 0$, reflects that Bertrand competition creates a welfare loss that must be corrected by increasing the tax of an equivalent amount. Such an increase in the tax on the conventional variety has a similar effect as a subsidy on the green variety. Conversely, a negative difference in profit margins corresponds to a welfare loss that must be offset by lowering the tax. As in Sandmo (1975), it is conceivable that the tax cut becomes so sharp that the optimal policy imposes to subsidize the conventional variety. Thus, the amount by which the optimal tax deviates from the standard Pigovian tax depends on the market conditions under unbridled Bertrand condition, namely, who is stealing the other's business and how distortive is the Bertrand equilibrium with respect to the social optimum.

Replacing p_1^R and p_2^U in (29) by the expressions of $p_1^B(\tau^*)$ and $p_2^B(\tau^*)$ given by (26) and (27) yields

$$\tau^* = \frac{3D'(X_1(\mathbf{p}^*) - 2(c_2 - c_1 - \beta)}{(1 + 3\lambda)}. \tag{30}$$

Obviously, the optimal level of the tax is both increasing with the severity of the polluting damage and decreasing with the marginal social value of the polluting variety. More precisely, τ^* is higher when buyers are more concerned with the environment or when the marginal cost of producing the green variety tends to that of producing the conventional variety. Furthermore, an increase in the marginal costs of public funds scales down the optimal tax.

The amount by which τ^* falls short of the benchmark level of the Pigovian tax is given by

$$\begin{aligned} (1+\lambda)\,\tau^* - D'(X_1(\mathbf{p}^*)) &= \frac{p_2^U}{\varepsilon_2(\mathbf{p}^*)} - \frac{p_1^R}{\varepsilon_1(\mathbf{p}^*)} \\ &= \frac{2}{1+3\lambda}\left(D'(X_1(\mathbf{p}^*) - (1+\lambda)(c_2 - c_1 - \beta)\right) \end{aligned} \tag{31}$$

Depending on the different combinations of the properties of the market and technology as well as the severity of the environmental damage, the regulator will not tackle the different market failures through the same channels. The alternative between a tax or a subsidy depends on whether or not the regulator chooses to foster business switching towards the green variety, or equivalently, whether the regulator needs to make the regulated producer more or less soft in the pricing game. Tables 1 and 2 below summarize the results for various parameter configurations.

State (1) of the economy:

When $c_2 - c_1 - \beta > 0$, the marginal social value of the polluting variety is positive for buyers and, from lemma 3, the market forces under unregulated Bertrand competition favor the conventional variety.

If, however, the parameter configurations satisfy $(1a)$, then the market left to itself induces the green producer to steal the polluting producer's clientele from the social standpoint. Thus, the regulator subsidizes the conventional variety to make business switch towards the polluting producer. This makes him tough in the pricing game and raises the green competitor's incentive to respond aggressively by lowering the price of the green variety. Subsidies to the conventional variety increase the intensity of price competition to encourage the demand for the conventional variety.

When parameter values fulfill $(1b)$, it is now the polluting producer who steals the other's clientele in the unregulated market, from the social standpoint. The regulator then uses a tax on the conventional variety to encourage buyers to switch towards the green variety. This makes the polluting producer less tough, thereby relaxing price competition. However, the tax evaluated at the shadow price of public funds is optimally set below the marginal damage, which, from (31), maintains in the regulated market the advantage in market power accruing to the polluting producer in the unregulated market. Hence, the environmental damage needs to be internalized only in part by the polluting producer. Taxes below the marginal damage mitigate price competition to make buyers switch towards the green variety.

If the environmental damage is so severe that ($1c$) holds, then the optimal tax exceeds the marginal damage. In this case, heavy taxation of the conventional variety forces the polluting producer to internalize into his decision making the detrimental effects of Bertrand competition on welfare. By making the polluting producer friendly in the pricing game, this policy restrains the green producer from pricing aggressively, while inducing buyers to switch towards the green variety. Note that by (31), the advantage in market power is now reversed relative to the unregulated situation. Taxes above the marginal damage make the conventional producer internalize the externality due to Bertrand competition and, by softening this competition, boost the demand for the green variety.

State (2) of the economy:

When $c_2 - c_1 - \beta < 0$, lemma 3 tells us that Bertrand competition favors the green variety in the unregulated market. Nevertheless, buyers value so little the conventional variety that regulation ought to encourage still further the demand for the green variety, regardless of the severity of the environmental damage. As in $(1c)$, taxes higher than the marginal damage are necessary to ensure that all the costs imposed on society, due to pollution and Bertrand competition, are factored into the polluting producer's decision making.

Table 1	$X_1(\mathbf{p}^B) - X_1(\mathbf{p}^*)$	τ^*
(1) $c_2 - c_1 - \beta > 0$		
$(1a)$ $D'(X_1(\mathbf{p}^*)) < \frac{2}{3}(c_2 - c_1 - \beta)$	$-$	$-$
$(1b)$ $\frac{2}{3}(c_2 - c_1 - \beta) < D'(X_1(\mathbf{p}^*)) < (1+\lambda)(c_2 - c_1 - \beta)$	$+$	$+$
$(1b)$ $(1+\lambda)(c_2 - c_1 - \beta) < D'(X_1(\mathbf{p}^*))$	$+$	$+$
(2) $c_2 - c_1 - \beta < 0$	$+$	$+$

Table 2	$(1+\lambda)\tau^* - D'(X_1(\mathbf{p}^*))$
(1) $c_2 - c_1 - \beta > 0$	
$(1a)$ $D'(X_1(\mathbf{p}^*)) < \frac{2}{3}(c_2 - c_1 - \beta)$	$-$
$(1b)$ $\frac{2}{3}(c_2 - c_1 - \beta) < D'(X_1(\mathbf{p}^*)) < (1+\lambda)(c_2 - c_1 - \beta)$	$-$
$(1b)$ $(1+\lambda)(c_2 - c_1 - \beta) < D'(X_1(\mathbf{p}^*))$	$+$
(2) $c_2 - c_1 - \beta < 0$	$+$

Explicit expressions are given in the Appendix.

4 Conclusion

This paper has analyzed the regulation of a polluting producer supplying a conventional variety that competes *à la* Bertrand with a green substitute provided by an unregulated rival. Buyers on the market are characterized by heterogeneous tastes for the design of varieties and the same aversion to pollution. The analysis of optimal pricing of the conventional variety yields that the Lerner index for the regulated producer is a weighted average of a standard Ramsey term which is inversely proportional to the elasticity of demand for the conventional variety and the marginal social cost due both to the environmental damage and the distortion associated with the exercise of market power by the green producer. This result means that the regulator ought to take into consideration, at the same time, several effects of the pricing by the polluting producer:

- the effect on the demand for the conventional variety and on the polluting producer's profit reflected by the Ramsey term,
- the effect on the pricing by the green competitor,
- and the effect in terms of environmental damage of the regulated activity.

To sum up, regulation affects the equilibrium prices of the differentiated varieties which, in turn, creates a socially desirable business switching between varieties. The efficient allocation of varieties is achieved by harnessing Bertrand competition.

In addition, the paper investigates optimal taxation of the conventional variety and evaluates the departures from the Pigovian principle, which would require to set the tax equal to the marginal damage from pollution were competition perfect. The alternative between a tax or a subsidy applied to the conventional variety depends on whether or not the regulator must encourage business switching toward the green variety by softening or strengthening price competition. If market conditions are such that the polluting producer steals his competitor's clientele with unbridled Bertrand competition, then the regulator must resort to a tax, and conversely. The tax on the conventional variety is explicitly shown to increase with the severity of the polluting damage and the buyer's aversion to pollution, and to decrease with the marginal savings from producing the conventional variety and the marginal costs of public funds.

These results highlight that the environmental concern can have significant effects on the stringency of taxation. As increased aversion to pollution softens Bertrand competition, it also allows the regulator to relax taxation. One policy implication is that the regulator may find worthwhile to enhance the environmental concern of buyers through information programs. This will be especially true if the regulator is reluctant to resort to high taxes for political or budget reasons.

Another extension would be to depart from the idea that regulation is an harmonized whole and consider instead noncooperative regulation of pollution and prices. In such a case, an environmental agency and a public utility commission, or an environment ministry and a trade ministry, would be responsible for regulating pollution and prices separately. Our model suggests that the objectives of the two regulators might be in conflict since, in some circumstances, the green producer is guilty of stealing the polluting producer's clientele from the social standpoint, although he has an environmentally desirable behavior.

5 Appendix

The market share of the polluting producer in Bertrand equilibrium of the regulated market is

$$X_1(\mathbf{p}^*) = \frac{1}{2} + \frac{1}{2t\,(1+3\lambda)}\left((1+\lambda)\,(c_2 - c_1 - \beta) - D'(X_1(\mathbf{p}^*)\right). \tag{32}$$

The twofold inequality $0 < X_1(\mathbf{p}^*) < 1$ holds for the following parameter configuration

$$(1+\lambda)\,(c_2 - c_1 - \beta) - t\,(1+3\lambda) < D'(X_1(\mathbf{p}^*)) < (1+\lambda)\,(c_2 - c_1 - \beta) + t\,(1+3\lambda)\,, \tag{33}$$

which, not surprisingly, amounts to (9) for $\lambda = 0$.

The divergence of the polluting producer's market share between the regulated and the unregulated market is

$$X_1(\mathbf{p}^*) - X_1(\mathbf{p}^B) = \frac{2\,(c_2 - c_1 - \beta) - 3D'(X_1(\mathbf{p}^*)}{6t\,(1+3\lambda)}. \tag{34}$$

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