Strategic Quality Competition and the Porter Hypothesis*

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Abstract

This paper offers new support for the Porter Hypothesis within the context of a quality competition framework. We use a duopoly model of vertical product differentiation in which two firms simultaneously choose to produce either a high (environmentally friendly) quality or low (standard) quality variant of the good, before engaging in price competition. In this simple setting, we show that a Nash equilibrium of the game featuring the low quality good can be Pareto dominated by a different strategy profile, in which both firms opt in favour of the "green" product. Our analysis demonstrates that, in such a case, both firms stand to profit from the introduction of a rule penalizing any firm refusing to produce the environmentally friendly product. We also find that consumers themselves may benefit from such regulations. This is always the case when shifting from low quality to high quality production brings about a cost efficiency improvement. Our main results are robust to a number of changes in the specifications of the model.

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1 Introduction

Conventional economic thinking suggests that introducing more stringent environmental regulations always implies some private costs, since it displaces firms from their first-best and forces them into a more compromised position. Porter [15], [16] challenged this view, claiming that just the opposite was true. His main argument, which was further elaborated in [17], was that environmental regulations can open up new investment opportunities, encourage companies to innovate and generate long-term gains that can partly or fully offset the costs of complying with them. This claim is now widely known as the Porter Hypothesis.

Porter's view has received a skeptical response from economists working within the bounds of standard economic theory. As Palmer [13] and others point out, the idea that firms might systematically overlook opportunities to innovate or routinely undermine their own efforts to improve results is difficult to reconcile with the neoclassical view of the firm as a rational profit-maximizing entity. Since firms are always willing to implement changes that they see as beneficial, if producing environmentally friendly products were really as profit-enhancing as Porter claims it to be, then they would have moved in that direction on their own and would need no governmental prompting.

In the face of such scepticism, other economists have recently depicted a number of scenarios for which the Porter result may hold. All of these studies point to the existence of some market failure that offers a field for environmental regulation, although different authors locate this failure at different levels in accordance with their specific interpretations of the Porter Hypothesis. Hart [9], for example, has shown that environmental regulations may help foster R&D activities and thus stimulate economic growth, while Simpson and Bradford [22] use an international trade model to show that tightening regulations may help shift profits from foreign to domestic firms because of the presence of international externalities. Similarly, Rothfels [20] demonstrates that enforced compliance with an environmental standard can push domestic firms to become leaders in the "green" market, thereby boosting their competitiveness vis-a-vis foreign rivals. Some intra-firm mechanisms through which environmental regulations can induce firms to make use of profit-enhancing innovations have also been studied. In this vein, Xepapadeas and de Zeeuw [24] conclude that more stringent environmental regulations can induce firms to downsize and modernize, while Popp [14] shows that firms tend to undertake risky R&D projects (many of which turn out to be ex-post profitable) only when regulations are in place. [2] suggests that environmental regulations can help narrow the information gap between firms and managers. Finally, Mohr [11] and Greaker [8] discuss inter-firm mechanisms through which tougher environmental policies can push a group of firms to invest in new pollution abatement techniques. In their papers environmental policy can benefit competitiveness by solving a coordination failure among firms.

These studies, like most of the related literature concerning the effects of environmental standards in industries (and most of the theoretical contributions to the Porter Hypothesis), have tended to focus exclusively on the supply side of the market (p. 281)[19].[1] By contrast, we suggest here that market demand –consumer preferences– may also favour the creation of a regulated environment in which firms stand to benefit from the sale of higher quality products at higher prices. Thus, in this paper we report an additional reason why a Porter-type result may emerge, that stems from consumer preferences.

The economic rationale behind our findings can be summarized as follows. Let us assume that the firms in a market produce a certain good of standard (low) environmental quality and that a new technique or innovation has recently become available, allowing for the production of a new, more environmentally friendly variant. In this context, each firm must decide whether to adopt the new technology or to stick with the old one. Since environmentally friendly products typically cost more to produce than do their standard variants, in an unregulated market many individual firms would most likely want to avoid making the foray into "green" production. While consumers are often willing to pay more for a cleaner product (see, for instance, [23]), the higher production costs would still put these firms at a price disadvantage vis-a-vis their competitors, since the latter would then be free to capture a large portion of the market by offering cheaper, low-quality variants of the same good. Were this same case to unfold in the context of a regulated market in which all firms adopted the high quality good, the result would be radically different. In this case, all of the firms would benefit from consumer willingness to pay higher prices and none would run the risk of being exploited by their competitors.

In game theory, this situation corresponds to a prisoner's dilemma in which the Nash

[1] One exception is [20], who explicitly considers the valuation of environmental quality by consumers.

equilibrium of the game is Pareto dominated by a different strategy profile which, however, is not an equilibrium (since all agents would have individual incentives to deviate from it). In the framework presented here, environmental regulation can motivate all firms to shift into "green" production in such a way that both the environment and the firms themselves are better off (hereafter denoted as a win-win situation).[2]

With regard to the economic forces behind this result, the closest papers in the literature are [11] and [8]. Although these two studies differ markedly from our own, the mechanisms behind the win-win result obtained by both authors also rest on a coordination failure, that is, on the disparity between individual firms' incentives for adopting the new technology and the interests of the industry as a whole.

As stated above, we use a standard Bertrand duopoly model of vertical product differentiation in which two firms must simultaneously choose to produce either the environmentally friendly or the standard variant of a given product, and then engage in price competition. This model is similar to the one used by Gabszewick and Thisse [7] and Shaked and Sutton [21],[3] in their seminal papers on the subject, except that here we treat environmental quality as a discrete variable rather than a continuous one. This would seem to be in keeping with our application context, since firms usually determine the environmental quality of their products through a series of discrete decisions (regarding whether to use conventional or recycled paper, fossil fuels or renewable energy, etc.). Since firms only have access to a discrete set of options and thus cannot be perfectly precise when adjusting their quality choices to those of their competitors, in many cases all of the firms in the market will set exactly the same quality standard at equilibrium.[4] This feature of

[2] Consider the following example. In the late 1990s, the European Union prohibited the production of leaded-petrol cars in Europe. Prior to that event, any manufacturer was free to focus its production exclusively on unleaded-petrol cars. Those who did so may have been putting themselves at a competitive disadvantage relative to their competitors, however, which continued to produce the less costly leaded-petrol cars. By forcing all manufacturers to produce only unleaded-petrol cars, the new regulations allowed all of these firms to benefit from consumers' higher willingness to pay for unleaded-petrol cars, without putting themselves at a cost disadvantage with respect to competing firms. The regulation of CFCs in the Montreal Protocol represents a similar situation.

[3] This kind of model has recently been applied to the study of environmental quality. See, for instance, [1] and [10].

[4] This contrasts with the results for models of price-quality competition with continuous quality, in which the equilibrium always involves a certain degree of product differentiation. See, for instance, [7] and

the model is a key determining factor to the emergence of a win-win result.

Economists have tended to support the Porter Hypothesis on the grounds that innovation sometimes leads to less costly production methods (see [17]). However, we suggest here that a win-win situation can arise even when the switch to environmentally friendly goods causes an increase in production costs. "Green" goods can be more expensive to produce, either because they require an initial investment in new materials and technologies or because they yield higher marginal costs. Despite the nature of the cost change is not crucial to obtain a win-win result, it is influential in determining to what extent regulation will ultimately have an impact on consumers. If fixed adoption costs represent a firm's only additional expense as a result of its decision to improve the environmental quality of its product, then consumers will always benefit from any regulations supporting such a move. This is because such fixed costs are always sunk and have no effect on market prices. But if the shift to a higher quality product entails higher marginal costs, then the prices paid by consumers will reflect that cost increment. Thus, in certain situations the improved quality of the environmentally friendly variant of a good does not compensate for the higher price to consumers.

The rest of this paper is organized as follows. Section 2 sets out the model. In Section 3, we solve for equilibrium prices and qualities in an unregulated market. Section 4 analyzes the conditions under which our model lends support to the Porter Hypothesis. In Section 5 we address the effects of environmental regulation on consumers. Section 6 considers the robustness of our results to a number of changes in the modelization. Finally, Section 7 situates our analysis within the context of the existing literature on the subject and offers some concluding remarks.

2 The Model

We consider a duopoly model of vertical product differentiation under complete information.[5] Here, two identical firms produce a good that can be vertically differentiated in

[21].

[5] The assumption of full information is standard in models of vertical product differentiation. However, environmental quality is not always directly observable by consumers. Eco-labelling schemes may help mitigate the potential asymmetry of the information received by consumers versus producers.

terms of environmental quality. Each firm chooses a specific environmental quality level s_i for their good, which can be either low ($i = L$), i.e., standard, or high ($i = H$), i.e., environmentally friendly.[6] Production costs are designated as $C_i(x) = F_i + c_i x^2$ ($i = H, L$), where x represents the output level and F_i, c_i are cost-specific parameters.[7] Assume that $F_H \geq F_L = 0$ (where the normalization $F_L = 0$ takes place without loss of generality) and that $c_H \geq c_L > 0$, since the environmentally friendly variant may cost more to produce than would the same amount of the standard (low quality) product. This potential cost elevation can appear in one of two ways. First, $F_H \geq 0$ meaning that shifting production in favour of an environmentally friendly good entails a fixed cost, which we interpret as an adoption cost (assumed to be sunk during the production stage). Or, secondly, $c_H \geq c_L$ implying that, for any given output, marginal costs are higher for environmentally friendly products (which require special details such as more demanding security standards, more expensive materials, etc.) than they are for standard products.

Finally, the willingness of consumers to pay for environmental quality is measured by the parameter θ, which is uniformly distributed over the interval $[0, 1]$ and for which the number of consumers is normalized to unity. That is, each consumer buys either one unit of the commodity or buys nothing at all. The indirect utility (or consumer surplus) of a type θ consumer is shown as $U_i = \theta s_i - p_i$ if she buys a good of environmental quality s_i at price p_i, and as zero if she buys nothing at all.

3 Price and Quality Competition

We are now in a position to analyze our game, which is divided into two stages. During the *first stage* of the game, two firms simultaneously set an environmental quality level for their goods. The resultant market will have one of three possible configurations: (i) both firms will produce the low quality variant of the good, (ii) both firms will produce the high quality variant or (iii) one firm will produce the low quality variant and the other firm will

[6] A natural interpretation, in line with Porter's original idea [15], [16], is that the product of higher quality only becomes available after some costly innovation process has taken place.

[7] The assumption that the quantity of the cost function is quadratic rather than linear is convenient for two technical reasons: (i) it ensures that both firms will always be active in equilibrium (provided that the fixed costs are low enough); (ii) it allows firms to have non-zero profits when they produce the same environmental variant of the product.

produce the high quality one. The two first cases give rise to a homogeneous good, while the third will produce a market with vertically differentiated goods. During the *second stage*, firms engage in price competition à la Bertrand.

3.1 The Price Competition Game

Let us solve the game backwards starting from the second stage, i.e., the price game. At this stage, each firm establishes a price for its product in accordance with the environmental quality levels chosen during the first stage.

First, we compute the demand functions for each quality mix. Since we have chosen to represent quality as a discrete choice, both symmetric and asymmetric quality must be considered here. We denote as p_{ij} and x_{ij} the price that has been set and the demand faced by a firm producing a good of quality s_i when its rival produces a good of quality s_j $(i,\, j = L, H)$. X_i represents the market demand for the good of quality s_i.

Let us first consider the case in which both firms offer goods of the same environmental quality, denoted as s_i. In this scenario, consumers have two alternatives: either they can buy one unit of the good or they can buy nothing at all. It will be optimal for type θ consumers to buy if and only if $\theta s_i - P_i \geq 0$, with P_i being the lowest available market price. Hence, the market demand for a good of environmental quality s_i comes from the consumer group with $\theta \geq \frac{P_i}{s_i}$, i.e., $X_i = \max\left\{1 - \frac{P_i}{s_i}, 0\right\}$ $(\, i = H, L)$. The demand function faced by firm a that sets price p^a_{ii} when its competitor b sets price p^b_{ii} can be expressed as follows:

$$x^a_{ii}\left(p^a_{ii}, p^b_{ii}\right) = \begin{cases} \max\left\{1 - \frac{p^a_{ii}}{s_i}, 0\right\} & \text{if } p^a_{ii} < p^b_{ii} \\ \frac{\max\left\{1 - \frac{p^a_{ii}}{s_i}, 0\right\}}{2} & \text{if } p^a_{ii} = p^b_{ii} \\ 0 & \text{if } p^a_{ii} > p^b_{ii}. \end{cases}$$

Secondly, let us consider the case in which the two firms produce goods of differing environmental quality levels. In this case, consumers can (i) buy one unit of the environmentally friendly variant, (ii) buy one unit of the standard variant or (iii) buy nothing at all. Let $\bar{\theta}_H \equiv \frac{p_{HL} - p_{LH}}{s_H - s_L}$ define the critical point of willingness at which the consumer is indifferent between the environmentally friendly good and the standard variant, and let $\bar{\theta}_L \equiv \frac{p_{LH}}{s_L}$ be the threshold at which the consumer is indifferent between the standard variant and not purchasing at all.

In this case, the demand for the high quality good is:[8]

$$x_{HL} = 1 - \bar{\theta}_H = 1 - \frac{(p_{HL} - p_{LH})}{(s_H - s_L)}, \tag{1}$$

and the demand for the low-quality good is:

$$x_{LH} = \bar{\theta}_H - \bar{\theta}_L = \frac{(p_{HL} - p_{LH})}{(s_H - s_L)} - \frac{p_{LH}}{s_L}. \tag{2}$$

We can now find the equilibrium of the price competition game for each of the relevant cases. When the environmental quality of both firms' good is s_i, the market structure will be characterized by two symmetric firms that engage in price competition over a homogeneous good. Let $\Pi_{ii}^a \left(p_{ii}^a, p_{ii}^b\right) \equiv p_{ii}^a x_{ii}^a \left(p_{ii}^a, p_{ii}^b\right) - C_i \left(x_{ii}^a \left(p_{ii}^a, p_{ii}^b\right)\right)$ denote the profits of firm a in this symmetric quality game when it sets price p_{ii}^a and its competitor sets price p_{ii}^b.

In the symmetric case, the equilibrium price characterization departs from that of the classic Bertrand paradox in which price is equal to marginal cost (the unique Nash equilibrium when the marginal costs are constant), due to the existence of strictly convex costs. In this regard, Dastidar [4] has proven that the Nash equilibria are necessarily non-unique in the context of a price competition model involving symmetric firms and strictly convex costs. Specifically, a pure strategy Nash equilibrium is characterized by both firms setting the same price p_{ii}^*, which is bounded by two thresholds, $\underline{p_i} \leq p_{ii}^* \leq \bar{p}_i$, where $\underline{p_i}$ (the lowest price compatible with an equilibrium) is defined as as the price that equals average variable costs, i.e., as the price at which firms are indifferent between producing at $\underline{p_i}$ and producing nothing at all; while $\bar{p}_i$ (the highest price compatible with a Nash equilibrium) is defined as the price at which each firm is indifferent between setting the equilibrium price $\bar{p}_i$, and hence split the demand evenly, and cutting marginally its price in order to exclude its rival and meet all of the existing demand.

For each game, the equilibrium price located in the interval $\left[\underline{p_i},\ \bar{p}_i\right]$ can be interpreted as an indication of the relative strength of the price competition between firms. Thus, competition can be seen to be toughest in games where $p_{ii}^* = \underline{p_i}$, and mildest in those where $p_{ii}^* = \bar{p}_i$. In this paper, we provide the following parametric way of representing the

[8] We are implicitly assuming that the fixed adoption costs are sunk during the price competition stage and that both firms are active, i.e., that $x_{HL} > 0$ and $x_{LH} > 0$. Formally, this latter condition implies that $\frac{p_{LH}}{s_L} < \frac{p_{HL} - p_{LH}}{s_H - s_L} < 1$. As we shall see, this always holds in equilibrium.

price, demand level and profits of a firm in equilibrium:

$$p_{ii}^* = \frac{c_i s_i}{c_i + (2-\alpha)\, s_i}, \qquad x_{ii}^* = \frac{s_i\,(2-\alpha)}{2\,(c_i + (2-\alpha)\, s_i)}, \qquad i = H, L, \tag{3}$$

$$\Pi_{ii}^* = p_{ii}^* x_{ii}^* - C_i\,(x_{ii}^*) = \frac{c_i s_i^2\,(2-\alpha)\,\alpha}{4\,(c_i + (2-\alpha)\, s_i)^2} - F_i, \;\; i = H, L, \tag{4}$$

Here, α can be interpreted as the (inverse of the) intensity of the price competition between firms, and can take values in the interval $\left[0, \frac{4}{3}\right]$. Specifically, $\alpha = 0$ corresponds to the case $p_{ii}^* = \underline{p_i}$, while $\alpha = \frac{4}{3}$ corresponds to $p_{ii}^* = \bar{p}_i$ and $\alpha = 1$ corresponds to the Bertrand reference case in which price is equal to marginal cost.[9] It is important to note here that the joint-profit maximizing price (i.e. the collusive price) can fall within this range of equilibrium prices. We rule out the economically unappealing case in which the Bertrand equilibrium price is higher than the collusive price, by stating that α must be smaller than or equal to $\hat{\alpha} \equiv \frac{2s_i + c_i}{s_i + c_i}$, where $\hat{\alpha}$ is the intensity of the rivalry between firms engaged in a price competition that leads to a collusive outcome. Hence, in what follows we will restrict to equilibria determined by the range $\alpha \in \left[0, \min\left\{\frac{4}{3}, \hat{\alpha}\right\}\right]$. In order to limit our number of cases, we assume that the intensity of this inter-firm competition is same for both quality choices.

When firms offering products of unequal quality engage in price competition, they choose p_{HL} and p_{LH} so as to maximize their profits:

$$\max_{p_{HL}} \Pi_{HL} = p_{HL}\left(1 - \frac{(p_{HL} - p_{LH})}{(s_H - s_L)}\right) - c_H \left(1 - \frac{(p_{HL} - p_{LH})}{(s_H - s_L)}\right)^2 - F_H$$

and

$$\max_{p_{LH}} \Pi_{LH} = p_{LH}\left(\frac{(p_{HL} - p_{LH})}{(s_H - s_L)} - \frac{p_{LH}}{s_L}\right) - c_L \left(\frac{(p_{HL} - p_{LH})}{(s_H - s_L)} - \frac{p_{LH}}{s_L}\right)^2.$$

The following reaction functions are obtained from the first order conditions:

$$\begin{aligned} p_{HL}\,(p_{LH}) &= \tfrac{(s_H - s_L)^2 + p_{LH}(s_H - s_L) + 2p_{LH}c_H + 2c_H(s_H - s_L)}{2(s_H - s_L) + 2c_H} \\ p_{LH}\,(p_{HL}) &= \tfrac{s_L^2 (s_H - s_L) p_{HL} + 2c_L s_H s_L p_{HL}}{2s_L s_H (s_H - s_L) + 2c_L s_H^2}. \end{aligned}$$

[9]The parameter α can be seen as a proxy of the competitiveness of the environment in which firms operate. If the market is characterized by fierce competition, then of all the possible equilibria the prevailing outcome will be one with a low value of α. Conversely, if firms operate in an environment in which competition is relatively weak, they will coordinate in an equilibrium with a high α. In Section 6 we present a modified version of the model in which this multiplicity of equilibria no longer exists.

Solving this system of equations involves obtaining the equilibrium prices and then deriving equilibrium quantities and profits directly from these prices.

For the firm producing the standard (low quality) variant of the product:

$$
\begin{aligned}
p^*_{LH} &= \frac{s_L\left(s_L\left(s_H - s_L\right) + 2c_L s_H\right)\left(s_H - s_L + 2c_H\right)}{\Lambda}, \\
x^*_{LH} &= \frac{s_L s_H\left(s_H - s_L + 2c_H\right)}{\Lambda}, \\
\Pi^*_{LH} &= \left(\frac{s_L\left(s_H - s_L + 2c_H\right)}{\Lambda}\right)^2 s_H\left(s_L\left(s_H - s_L\right) + c_L s_H\right).
\end{aligned}
$$

For the firm producing the environmentally friendly (high quality) variant of the product:

$$
\begin{aligned}
p^*_{HL} &= \frac{2s_H\left(s_L\left(s_H - s_L\right) + c_L s_H\right)\left(s_H - s_L + 2c_H\right)}{\Lambda}, \\
x^*_{HL} &= \frac{2s_H\left(s_L\left(s_H - s_L\right) + c_L s_H\right)}{\Lambda}, \\
\Pi^*_{HL} &= \left(\frac{2s_H\left(s_L\left(s_H - s_L\right) + c_L s_H\right)}{\Lambda}\right)^2 \left(s_H - s_L + c_H\right) - F_H,
\end{aligned}
$$

where $\Lambda \equiv 4s_H\left(s_L\left(s_H - s_L\right) + s_L c_H + s_H c_L + c_L c_H\right) - s_L\left(s_L\left(s_H - s_L\right) + 2s_L c_H + 2s_H c_L\right) > 0$. It is easy to check that prices and quantities are always positive in equilibrium.

3.2 Quality Choice Game

During the first stage of our game, duopolists set the environmental quality level (s_L or s_H) of their products, taking into account the consequences of this decision for the second stage. These decisions can be summarized as a simultaneous game in normal form:

		Firm 2: s_H	Firm 2: s_L
Firm 1	s_H	(Π^*_{HH}, Π^*_{HH})	(Π^*_{HL}, Π^*_{LH})
	s_L	(Π^*_{LH}, Π^*_{HL})	(Π^*_{LL}, Π^*_{LL})

(5)

The prevailing quality mix will be the Nash equilibrium of this game.

We should point out that since quality is represented as a discrete choice, firms are less able to differentiate their products from those of their competitors. This implies that there might be situations in which, at equilibrium, there is no vertical differentiation. As the following section shows, this possibility turns out to be a key to our results.

4 Environmental Regulation

This section seeks to answer two key questions: can environmental regulations *ever* be seen to benefit both firms? And if so, what are the economic driving forces behind such a result?

Let us assume that the government implements a new policy designed to promote the use of more environmentally friendly technologies in order to discourage the production of the standard (low quality) variants of a given good. For the sake of simplicity, let us assume that the policy involves imposing a basic penalty or lump-sum tax (T) on any firm choosing to produce the standard variant of the good. This lump-sum tax can also be interpreted as a license that must be purchased by any firm wishing to produce goods of quality s_L.[10]

For a given amount of tax T, the regulated quality choice game can be represented in normal form as follows:

Firm 2

Firm 1		s_H	s_L
	s_H	(Π^*_{HH}, Π^*_{HH})	$(\Pi^*_{HL}, \Pi^*_{LH} - T)$
	s_L	$(\Pi^*_{LH} - T, \Pi^*_{HL})$	$(\Pi^*_{LL} - T, \Pi^*_{LL} - T)$

(6)

We are now in a position to show how our model of vertical product differentiation can actually yield a win-win result, thus providing further support for the Porter Hypothesis. The economic rationale behind this result can be explained as follows. If the firms in our model are stuck at an equilibrium that is Pareto inefficient, then the new environmental policy may lead to a profit-enhancing outcome for both firms. In particular, consider a situation where firms are producing a good with a low environmental quality (s_L) and there is a more environmentally friendly alternative available (s_H). In this case, even though all of the firms would benefit from a group decision to adopt the higher quality good, no individual firm would be likely to do so since such a move would potentially expose it to the opportunistic behavior of its competitors (which could then go on to market the

[10] All of the relevant results are compatible with other environmental policy instruments. The simplest and most straightforward alternative to this strategy would be to impose a technological standard that forces firms to adopt the new technology. A more complex regulation based on effluent taxes is considered in Section 6.

cheaper, low quality good at a lower price, thereby capturing a large share of the market). In this scenario, environmental regulation could open the door to a win-win situation by motivating both firms to take on the "green" good, to their own benefit and that of the environment. This intuition can be formalized in the following definition.

Definition 1 *An environmental policy will lead to a **win-win situation** if the Nash equilibrium of the regulated quality choice game results in higher payoffs for both firms than those obtained by a Nash equilibrium of the unregulated game.*

In theory, the definition of a win-win situation is compatible with any equilibrium configuration, but the above reasoning suggests that this result occurs when the equilibrium of the game shifts from (s_L, s_L) in the absence of environmental regulation to (s_H, s_H) once regulations have been implemented. The following proposition confirms this intuition.

Proposition 1 *(**Necessary Condition**) An environmental policy (characterized as a rule that imposes the penalty $T > 0$ on any firm choosing to produce the environmentally damaging variant of the good) can yield a **win-win situation** only if (s_L, s_L) is a Nash equilibrium of the quality choice game (5) and (s_H, s_H) is the unique Nash equilibrium of the regulated quality choice game (6).*

The proof of Proposition 1 can be developed as follows. First, in order to obtain a win-win result, the initial equilibrium of the game must differ from the final one. Otherwise, regulation would have no impact on the profits of firms producing with high quality, and would decrease the profits of those that produce with low quality. Next, we can see that a win-win situation will never occur if the environmental policy induces only one firm to change its strategy. This is a simple matter of revealed preference, since this strategy change was already available in the unregulated game and no firm find it optimal to alter its strategy. The need for a simultaneous strategy shift, and the fact that the firms are identical, means that a win-win situation can only arise when environmental regulations induce firms to move from the equilibrium (s_L, s_L) to the equilibrium (s_H, s_H).

From Proposition 1 it is immediate to obtain the following result, which provides us with the conditions that are necessary and sufficient to bring about an increase in firm profits as a result of environmental regulation.

Corollary 1 ***(Necessary and Sufficient Conditions)*** *Environmental regulation will yield a* ***win-win situation*** *if and only if both of the following conditions hold:*

(1) $T > \max\{\Pi^*_{LL} - \Pi^*_{HL}, \Pi^*_{LH} - \Pi^*_{HH}\}$

(2) $\Pi^*_{HL} < \Pi^*_{LL} < \Pi^*_{HH}$.

Condition 1 requires that the tax be high enough to make (s_H, s_H) the only possible Nash equilibrium of the regulated quality choice game. In this context, $T > \Pi^*_{LH} - \Pi^*_{HH}$ is needed to produce the desired equilibrium, and $T > \Pi^*_{LL} - \Pi^*_{HL}$ is also needed to prevent (s_L, s_L) from becoming an equilibrium. Condition 2 is twofold. The first inequality ensures that (s_L, s_L) will be an equilibrium of the unregulated game. The second inequality ensures that both firms would be better off if they simultaneously switched from the low to the high quality variant of the product.

It is straightforward to see that Condition 1 always holds, provided the value of T is sufficiently high. Thus, Condition 2 is the crucial one to the emergence of a win-win situation.

Two slightly different case scenarios can be extrapolated from this description. On the one hand, we can assume that not only Condition 2 but also $\Pi^*_{LH} > \Pi^*_{HH}$ holds in the unregulated quality choice game (5), making $(s_L,\ s_L)$ the unique Nash equilibrium of the game. This corresponds to a classical prisoner's dilemma in which the new environmental policy serves to advance firm interests by pushing the latter away from an undesirable equilibrium. On the other hand, we might assume that $\Pi^*_{LH} < \Pi^*_{HH}$ instead. In this case, the unregulated game has two equilibria –$(s_L,\ s_L)$ and $(s_H,\ s_H)$– and the environmental policy works to discourage the production of low quality goods, to eliminate the multiplicity of equilibria and to ensure the prevalence of a "good" outcome.

After this general presentation of the mechanism supporting the Porter Hypothesis, the question remains as to whether our model of vertical differentiation can actually replicate this theoretical possibility. The following discussion gives two numerical examples in which we are able to prove this possibility.

Example 1 *(Differences in marginal costs)*

Let us imagine that the publishers in a given market must choose either to continue using regular paper (s_L) or to start printing on recycled paper (s_H). While those opting to "green" their product would not have to buy new presses or other tools in order to do so, they would face higher input costs (i.e., they would have to buy recycled paper a higher price). In other words, the quality shift would bring about an increase in marginal costs but no fixed adoption expenses. Let us assume that this market is a duopoly characterized by the following parameter configuration and the associated payoff matrix for the quality-choice game:

$$(s_H, s_L, F_H, F_L, c_H, c_L, \alpha) = (300, 260, 0, 0, 500, 100, 1)$$

		Firm 2	
		s_H	s_L
Firm 1	s_H	(17.58, 17.58)	(9.95, 27.79)
	s_L	(27.79, 9.95)	(13.04, 13.04)

This game presents a typical prisoner's dilemma paradigm in which the unique Nash equilibrium, (s_L, s_L), is inefficient from an industry point of view, since both groups of publishers stand to benefit from a general agreement to use only recycled paper. However, the latter outcome is not a Nash equilibrium, since each firm has incentives to deviate from it.

Now assume that the government imposes a fix penalty T on any publishers that continue to use regular paper, thereby reducing the payoffs of some firms but increasing those of none. At first sight, the policy would seem to be entirely unfavorable to the industry as a whole. Nevertheless, it is immediate to check that, for any $T > 10.21$, the Nash equilibrium of the game changes to (s_H, s_H). If we compare the pre- and post-regulation equilibrium outcomes, we will find that the profits of both publishers increase when the penalty is imposed.

Example 2 *(The fixed cost of adopting a new technology)*

Now let us consider an industrial market in which the manufacturers of a certain product use engines run by a highly polluting fossil fuel (s_L). These firms have the option to switch to a cleaner fuel (s_H) that carries the same unit cost and heat power as the polluting one, but that requires the installation of new engines. In this case, the environmental quality increase does not affect variable costs, but does involve a fixed adoption cost (the purchase of a new engine). Let us also assume the following parameter values and associated payoff matrix:

$$(s_H, s_L, F_H, F_L, c_H, c_L, \alpha) = (110, 100, 0.7, 0, 200, 200, 1.3)$$

		Firm 2	
		s_H	s_L
Firm 1	s_H	(6.48, 6.48)	(6.15, 5.42)
	s_L	(5.42, 6.15)	(6.24, 6.24)

In this case, both (s_L, s_L) and (s_H, s_H) represent Nash equilibria. The fact that the latter Pareto dominates the former provides some scope for the possibility of a win-win result: thus, environmental policy solves the coordination failure, eliminates the multiplicity of equilibria and ensures that a "beneficial" equilibrium will prevail. In particular, it suffices to set $T > 0.09$ to induce a quality choice game in which the only Nash equilibrium is $(s_H,\ s_H)$.

The above examples show that a Porter-type result can emerge regardless of the nature of the cost increase generated by any given quality improvement. As we mentioned earlier, such a result is directly dependent on Condition 2 in Corollary 1. Using the analytical expressions for the equilibrium profits computed in Subsection 3.1, Condition 2 can be rewritten as follows:

$$\begin{array}{c} \left(\frac{2s_H(s_L(s_H-s_L)+c_Ls_H)}{\Lambda}\right)^2 (s_H - s_L + c_H) - F_H < \\ \frac{c_L s_L^2 (2-\alpha)\alpha}{4(c_L+(2-\alpha)s_L)^2} < \frac{c_H s_H^2 (2-\alpha)\alpha}{4(c_H+(2-\alpha)s_H)^2} - F_H \end{array} \tag{7}$$

The following proposition shows that, for any given value of s_L, c_H, c_L and F_H, this condition can be expressed as a lower and upper bound for s_H. To present this result, let us first define two thresholds: (i) $\hat{s}_H \equiv \frac{c_H\sqrt{\frac{4F_H}{\alpha(2-\alpha)c_H}+\frac{c_L s_L^2}{(c_L+(2-\alpha)s_L)^2 c_H}}}{1-(2-\alpha)\sqrt{\frac{4F_H}{\alpha(2-\alpha)c_H}+\frac{c_L s_L^2}{(c_L+(2-\alpha)s_L)^2 c_H}}}$ and (ii) $\tilde{s}_H$ that is implicitly determined as the solution to $\Pi^*_{HL} = \Pi^*_{LL}$.

Proposition 2 *Assume $F_H \geq 0$ and $c_H \geq c_L$. For any $(s_L, c_H, c_L, F_H, \alpha) \in \mathbb{R}^5_{++}$ there exist two thresholds $\hat{s}_H$ and $\tilde{s}_H$ such that environmental regulations (values of T) will yield a win-win situation if and only if $\hat{s}_H < s_H < \tilde{s}_H$.*

Proof. *See Appendix.* ■

Proposition 2 implies that the quality of the environmentally friendly product must be high enough to bring about a profit increase for both firms, but low enough to rule out the possibility that firms choose this level of quality in the unregulated market for that product.

This means that a win-win situation can only emerge when s_H takes an intermediate value that is neither too high nor too low. Nevertheless, the proposition gives no clue as to what "intermediate" may mean nor as to the specific relationship between low and high environmental quality standards. A natural way to probe deeper into this result is to focus on the relative cost-efficiency of both quality variants as measured by the ratio $\frac{s_i}{c_i}$.

Consider, first of all, an environment like the one depicted in Example 1, where the cost of assimilating the high quality good is limited to higher marginal costs ($c_H > c_L$ and $F_H = 0$). The following corollary proves that, in this setting, a win-win situation cannot arise if the high quality product proves to be more cost-efficient than the low quality product for values of α not exceeding that of the Bertrand reference case of marginal cost pricing.

Corollary 2 *Assume $F_H = 0$, $c_H > c_L$ and $\alpha \leq 1$. If producing the environmentally friendly product is more cost-efficient than producing the low variant quality of the product, then environmental regulation never generates a win-win situation. Formally, if $\frac{s_H}{c_H} \geq \frac{s_L}{c_L}$ then Condition 2 in Corollary 1 will never hold, since $\Pi^*_{HL} > \Pi^*_{LL}$.*

Proof. *See the Appendix.* ∎

The intuition behind this result can be stated as follows. In order for a win-win situation to arise in the unregulated game, no individual firm must have an incentive to adopt production of the high quality good. If one firm chose to differentiate its product, the price competition between the firms would relax. If, despite this positive effect, firms continue to produce the cheaper, standard variant of the good, it can only be because the cost of shifting to a high quality product outweighs any foreseeable gains to be had as a result of the less competitive market context. Hence, a win-win result requires that the cost of producing the environmentally friendly product be sufficiently high relative to that of the low quality alternative ($c_H > \frac{s_H}{s_L} c_L$).

It is important to point out that some of the arguments in favour of the Porter Hypothesis provided in [16] and [17] rest on the fact that innovation can sometimes lead to more cost-efficient production methods. Corollary 2 shows that this need not be the case in our model, which in turn reinforces our idea that our win-win result rests on a demand-side mechanism (consumer preferences for cleaner goods) rather than on any productivity gain or cost savings brought about by regulation.

Let us now illustrate the region in which environmental regulation can sustain a win-win result for the particular parameter configuration in Example 1:

[Insert Figure 1]

Figure 1 shows that the range of values for s_H compatible with a win-win situation depends non-monotonically on s_L. For very low values of s_L, a win-win situation is never feasible. As s_L increases, the win-win range for s_H initially widens but then narrows as the value of s_L increases accordingly. Moreover, the figure also illustrates how the range of parameter values for which a Porter result emerges is incompatible with the environmentally friendly product being more cost-efficient than the low quality one.

Nevertheless, in a less competitive environment, (when α sufficiently high) win-win policies can arise even when the the environmentally friendly product is more cost-efficient, as the following example illustrates.

Example 3 *(Differences in marginal costs and cost-efficient high quality)*

Assume the following parameter values and associated payoff matrix:

$$(s_H, s_L, F_H, F_L, c_H, c_L, \alpha) = (191.1, 172, 0, 0, 63, 60, 4/3)$$

Firm 2

		s_H	s_L
Firm 1	s_H	(14.1, 14.1)	(12.92, 8.69)
	s_L	(8.69, 12.92)	(12.93, 12.93)

It is easy to see that the high quality is more cost-efficient since $3.03 = \frac{s_H}{c_H} > \frac{s_L}{c_L} = 2.87$, yet there is still room for a win-win policy provided that $T > 0.01$.

Finally, consider an environment such as the one described in Example 2, in which $c_H = c_L \equiv c$ and the only difference between low and high quality production is that the latter entails an extra fixed adoption cost ($F_H > 0$). In this case win-win policies are trivially compatible with a more cost-efficient high quality production choice since, by assumption, $s_H > s_L$, meaning that $\frac{s_H}{c_H} > \frac{s_L}{c_L}$ always holds.

5 Market Coverage and Consumer Surplus

This section investigates the impact of environmental policy on consumer surplus and demand coverage (i.e., the portion of consumers who decide to enter the market), focusing on those environmental regulations that tend to benefit firms. This issue is far from trivial: although consumers prefer environmental quality, consuming the environmentally friendly products may be more expensive.[11]

Some authors have argued that environmental regulations can generate scarcity rents, causing benefits to shift from consumers to firms (see [6] for a general discussion or [12] for an explicit link to the Porter Hypothesis). Consequently, one might expect that any environmental policy that benefits firms will always have a negative effect on consumers. We claim that this need not be the case. Specifically, this section shows that an environmental policy can simultaneously increase firm profits and consumer surplus while also expanding the number of active consumers in the market. In other words, we argue here that environmental regulation has the potential to unambiguously enhance overall efficiency.

We start by presenting the following two lemmas.

Lemma 1 *The number of active consumers when both firms set a quality of s_i is greater than that when both firms set a quality of s_j $(i,j = L,H)$ if and only if quality s_i is more cost efficient than quality s_j, i.e.*

$$X_i > X_j \Leftrightarrow \frac{s_i}{c_i} > \frac{s_j}{c_j} \qquad i,j = L,H.$$

The proof of this lemma is straightforward. As shown in Subsection 3.1, the market demand for a good with environmental quality s_i (s_j) is given by the mass of consumers with $\theta \geq \frac{P^*_{ii}}{s_i}$ $(\theta \geq \frac{P^*_{jj}}{s_j})$. Using the expression for the equilibrium prices in (3) to compare the two market demands, Lemma 1 is directly obtained.

Lemma 2 *If the environmentally friendlier product is more cost-efficient than the low quality good (i.e., $\frac{s_H}{c_H} > \frac{s_L}{c_L}$), the surplus of every active consumer in the market will be greater in a (s_H, s_H) equilibrium than in a (s_L, s_L) equilibrium.*

Proof. *See the Appendix.* ■

[11] Crampes and Hollander [3] show that, for a model with continuous quality, the effect of a minimum quality standard on consumer welfare will depend on the quality response of the firm producing the high quality good.

The combined effect of these two lemmas will ensure that if "greening" a product implies a cost-efficiency improvement, then the implementation of a strict environmental policy will provide a two-fold benefit to consumers. First, it brings new consumers to the market who, with the low-quality variant, were reluctant to purchase the good. Second, it will increase the surplus of existing customers.

We should note here that the converse to Lemma 2 is not true. If $\frac{s_H}{c_H} < \frac{s_L}{c_L}$, then a policy that induces firms to adopt the high quality product will undoubtedly harm some consumers, by driving them out of the market. Nevertheless, it may still benefit others (those who are more willing to pay for environmental quality).

When the shift to a higher quality product only involves a fixed adoption cost ($F_H > 0$, $c_H = c_L$), $\frac{s_H}{c_H} > \frac{s_L}{c_L}$ trivially holds. Therefore, Lemmas 1 and 2 give rise to the following result:

Proposition 3 *Assume that $F_H > 0$ and $c_H = c_L \equiv c$. A shift from (s_L, s_L) to (s_H, s_H) will (1) increase demand coverage (2) increase the surplus of every consumer in the market.*

Note that Proposition 3 represents a general result, in the sense that it does not rely on how firm profits change, but only on the quality shift. Consumers will always benefit from an increase in the quality of the goods provided, even if this change does not profit firms. This is related to the fact that, since equilibrium prices depend only on marginal costs and not on fixed costs, shifting from s_L to s_H will give consumers a higher quality product with the same marginal cost, a clearly positive result. In this case, environmental regulation that induces firms to shift from a (s_L, s_L) equilibrium to a (s_H, s_H) equilibrium can unambiguously improve efficiency, since all of the economic agents involved (firms and consumers) will be better off and environmental quality of the products will also be higher.

Unfortunately, the impact on consumers is less positive when such a shift results in higher marginal costs, since the market price of the new (environmentally friendly) product will necessarily reflect this marginal cost increase. As a matter of fact, Proposition 4 will show that, for low values of the parameter α, any environmental policy that has a beneficial effect on firms will always carry the negative effect of crowding some consumers out of the market.

Proposition 4 *Assume that $F_H = 0$, $c_H > c_L$ and $\alpha \leq 1$. Any environmental regulation that generates a win-win situation has the following implications: (1) it reduces demand coverage (2) it decreases the surplus of at least some consumers in the market.*

This result is a direct consequence of Corollary 2 and Lemma 1. Corollary 2 ensures that, whenever $\alpha \leq 1$, a win-win policy necessarily requires that $\frac{s_H}{c_H} < \frac{s_L}{c_L}$. This, together with Lemma 1, implies that some consumers will be crowded out by the quality shift and, hence, that they will be negatively affected by the policy. The intuition for this result can be explained as follows. In a relatively intense price competition, environmental policy can benefit firms only when the advantage of producing the high -rather than the low- quality product is relatively small (see Corollary 2). Since market interaction causes firms to resist adopting the environmentally friendly product in such cases, regulation can help solve this problem by giving firms a necessary push forward. However, since the advantages associated with this switch are relatively small, the quality increase may not compensate for the higher price and consumers may end up enjoying a lower surplus.

Even when moving into environmentally friendly production entails higher marginal costs, there is still room for policies that simultaneously benefit both firms and consumers. In particular, one can construct examples for contexts characterized by weak price competition (where α sufficiently high) in which the environmental policy yields higher firm profits, larger market coverage and increased surplus of all the consumers. To illustrate this, we need only recall Example 3 in which a win-win result with a high quality and cost-efficient product was obtained. In this case, Lemmas 1 and 2 directly apply, ensuring that when firms move from the low quality to the high quality equilibrium, not only new consumers enter the market but the surplus of every active consumer of the good in question will also increase.[12]

[12] At this point, it should be noted that there is no monotonic relationship between the degree of price competition and the impact of the environmental policy on consumers. In fact, for the reference case of marginal cost pricing ($\alpha = 1$), it can be shown that any environmental policy that increases firm profits will decrease the surplus of every consumer in the market. The details of the proof are available in the Working Paper version of the article.

6 Some Extensions

6.1 Effluent taxes

Thus far, we have assumed that the government will use a simple instrument (a lump-sum tax) to persuade firms to adopt the environmentally friendly product. We now consider whether the possibility of obtaining a win-win result is robust to the use of a more realistic policy instrument, such as an effluent tax. To do so, we model a situation in which producers of standard (low environmental quality) goods must pay a tax $t > 0$ per unit produced. We implicitly assume that production level serves as a proxy for the level of environmental damage, and that the high quality good does not pollute.

Here, as earlier, we analyze a two-stage game. In the *first stage* of the game, firms simultaneously set an environmental quality level for their products, and afterwards engage in price competition. Let Π_{ij}^{t} denote the profit of a firm that sets quality s_i, when it competitor chooses s_j $(i, j = H, L)$ and a tax t is imposed on those units produced of the good of low environmental quality.

Consider, first, the case in which the firms offer products of same environmental quality s_i. If both of them decide to produce the environmentally friendly good, then Π_{HH}^{t} will coincide with that in (4), since no tax is paid. If, however, both firms decide to produce the standard (low quality) variant of the good, profits will move from the expression in (4) to

$$\Pi_{LL}^{t} = \frac{c_L (s_L - t)^2 (2 - \alpha) \alpha}{4 (c_L + (2 - \alpha) s_L)^2},$$

where, as was the case before, α can be interpreted as the (inverse of the) intensity of the price competition and takes values in the interval $\left[0, \frac{4}{3}\right]$. As expected, Π_{LL}^{t} is always decreasing in t. Moreover, there is a threshold for the tax rate, $\bar{t}^{LL} \equiv s_L$, such that if $t > \bar{t}^{LL}$ then the firms will decide not to produce at all.

In the case where the firms set goods of differing environmental qualities, they choose p_{HL}^{t} and p_{LH}^{t} so as to maximize profits:

$$\max_{p_{HL}^{t}} \Pi_{HL}^{t} = p_{HL}^{t} \left(1 - \frac{(p_{HL}^{t} - p_{LH}^{t})}{(s_H - s_L)}\right) - c_H \left(1 - \frac{(p_{HL}^{t} - p_{LH}^{t})}{(s_H - s_L)}\right)^2 - F_H$$

and

$$\max_{p_{LH}^{t}} \Pi_{LH}^{t} = \left(p_{LH}^{t} - t\right) \left(\frac{(p_{HL}^{t} - p_{LH}^{t})}{(s_H - s_L)} - \frac{p_{LH}^{t}}{s_L}\right) - c_L \left(\frac{(p_{HL}^{t} - p_{LH}^{t})}{(s_H - s_L)} - \frac{p_{LH}^{t}}{s_L}\right)^2.$$

Computations analogous to those in Section 3.1 yield the following expressions for firm profits:

$$\Pi^t_{LH} = \left(\frac{s_L\left(s_H - s_L + 2c_H\right) - t\left(2s_H - s_L + 2c_H\right)}{\Lambda}\right)^2 s_H\left(s_L\left(s_H - s_L\right) + c_L s_H\right)$$

and

$$\Pi^t_{HL} = \left(\frac{2s_H\left(s_L\left(s_H - s_L\right) + c_L s_H\right) + t s_H s_L}{\Lambda}\right)^2 \left(s_H - s_L + c_H\right) - F_H,$$

with Λ as defined in Section 3.1.

It is direct to see that Π^t_{HL} is increasing in the tax rate, while Π^t_{LH} is decreasing in it. Moreover, as in the symmetric quality case, there is a threshold for t, $\bar{t}^{LH} \equiv \frac{s_L(s_H - s_L + 2c_H)}{(2s_H - s_L + 2c_H)}$, such that, if $t > \bar{t}^{LH}$, then the firm producing the low quality good will cease to produce.

In order to check whether a win-win situation will be possible under an effluent tax, we need to verify whether the translation of the necessary and sufficient conditions in Corollary 1 to this setting holds. More precisely, a Pigouvian tax on production will yield a win-win situation if and only if both of the following conditions hold:

(a) The tax rate t is such that: $\Pi^t_{HL} > \Pi^t_{LL}$ and $\Pi^t_{HH} > \Pi^t_{LH}$.

(b) In the absence of taxes: $(\Pi^t_{HL})_{|t=0} < (\Pi^t_{LL})_{|t=0} < (\Pi^t_{HH})_{|t=0}$.

These two conditions merely reinstate the original ones: (a) requires that (s_H, s_H) be the only Nash equilibrium of the regulated quality choice game; and (b) requires that there be an equilibrium of the unregulated game such that both firms choose to provide the lesser quality product, although both firms would be better off were they both to produce the environmentally friendly product.

The possibility of obtaining a win-win result turns out to be fully robust to this change in the policy instrument. The argument can be sketched as follows. First, Condition (b) is independent from the policy being implemented. It depends on the parameter configuration, and values can always be found to fulfill it, as shown in Examples 1 and 2. We now argue that one can find a tax rate t such that Condition (a) also holds. It suffices to take into account that Π^t_{HL} is increasing in t, that Π^t_{HH} does not depend on t, and that both Π^t_{LH} and Π^t_{LL} are decreasing in t. This allows us to ensure that there exists a sufficiently high value of t such that both firms will be induced to shift their production in favour of the environmentally friendly product.

The conclusion to be drawn from the above examples is that in a model like ours, featuring discrete qualities and price competition, whether or not the Porter Hypothesis will hold does not depend on the exact nature of the regulatory instrument (a lump-sum tax, a minimum quality standard or even an effluent tax).

6.2 Vertical and horizontal product differentiation

Thus far, we have assumed that the only differentiating factor between the variants of a given good is that associated with environmental quality and that, therefore, when both firms choose to produce goods of the same environmental technology consumers are totally indifferent between purchasing products from one or the other firm. In this section, we explore the impact of other differentiating details (brand names, locations, etc.) which make goods of equal environmental quality into imperfect substitutes of each other. Specifically, we question how this may affect the possibility of obtaining a win-win result in an environmentally regulated context. To answer this question, we check the robustness of our main result to the introduction of a horizontal differentiation dimension to the existing context of vertical differentiation.

This possibility can be modelled by assuming that there are two firms located at opposite ends of a “linear city” of length 1, which are otherwise identical. Let us label the firms as 0 and 1, according to their respective locations. Here, as in our earlier sections, each firm must first set a specific environmental quality level (which can be either high or low) for its good, before engaging in price competition with the other firm.

Consumers are distributed uniformly along the city. An individual located in $y \in [0, 1]$ enjoys a utility from buying a good with quality s_0 from firm 0 equal to $U_0 = (1 - y)\, s_0 - p_0$, and a utility from a good with quality s_1 bought from firm 1 equal to $U_1 = ys_1 - p_1$, where $s_0, s_1 \in \{s_L, s_H\}$. The parameter y reflects the consumer’s bias towards each firm. There is still a vertical differentiation component here, since the higher the quality of any firm’s good, the higher the utility to be obtained by each person consuming that good.

It is immediate to compute the demand faced by each firm, which is given by:[13]

$$D_0 = \frac{s_0 + p_1 - p_0}{s_0 + s_1}; \qquad D_1 = \frac{s_1 + p_0 - p_1}{s_0 + s_1}.$$

[13] As is often the case for models of horizontal differentiation, we assume here that the market is fully covered to avoid the existence of local monopolies and ensure effective competition.

The objective function of each firm $z = 0, 1$ is:

$$\max_{p_z} \Pi_z = p_z D_z - c_z (D_z)^2 - F_z,$$

with $F_z = 0$ ($F_z = F_H$) for the firm producing the low (high) environmental quality good.

Some straightforward computations yield the following equilibrium values for firm 0:

$$p_0^* = \frac{(s_0 + s_1 + 2c_0)(2s_0 + s_1 + 2c_1)}{3(s_0 + s_1) + 2(c_0 + c_1)},$$
$$D_0^* = \frac{2s_0 + s_1 + 2c_1}{3(s_0 + s_1) + 2(c_0 + c_1)},$$
$$\Pi_0^* = \left(\frac{2s_0 + s_1 + 2c_1}{3(s_0 + s_1) + 2(c_0 + c_1)}\right)^2 (s_0 + s_1 + c_0) - F_0.$$

The expressions for firm 1 can be directly obtained by symmetry.

It can be shown that, in this alternative setting featuring imperfect substitutes, a win-win result can still arise. Since the two firms are symmetrically located in the linear city, we can retrieve the original notation and label each firm by the quality of its product, instead of by its location. Thus, it is immediate to observe that the reasoning behind Corollary 1 also applies in this setting. On the one hand, Condition 1 does not depend on the exact functional form of the firm profits and, hence, one can always find values of T such that it is fulfilled. Therefore, Condition 2 remains the crucial one.

Let us focus first on the case where the environmentally friendly product conveys higher marginal costs. First, it is straightforward to see that $\Pi_{HH} > \Pi_{LL}$ for any value of $s_H > s_L$. Second, it can be proved that a threshold exists for s_H, denoted $\bar{s}_H$, such that $\Pi_{HL} < \Pi_{LL}$ for every $s_H < \bar{s}_H$.[14]

In the scenario where the production of the high environmental product requires some fixed adoption costs, it is also easy to show that for any parameter configuration there are values of the fixed cost F_H that are compatible with a win-win result.[15]

Although our analysis in this subsection rests on a particular (and less standard) model, we believe it provides us with two valuable insights. First, it shows that win-win situations

[14]The existence of this threshold can easily be shown from the fact that (i) if $s_H \to s_L$ then Π_{HL} is strictly smaller than Π_{LL}, and (ii) Π_{HL} is monotonically increasing in s_H and approaches infinity when $s_H \to +\infty$.

[15]A sufficient condition that ensures the existence of values of F_H that are compatible with a win-win result is that $\Pi_{HL} < \Pi_{HH}$. This inequality is fulfilled, since $\Pi_{HL} - \Pi_{HH}$ is decreasing in s_H and $\lim_{s_H \to s_L} (\Pi_{HL} - \Pi_{HH}) = 0$.

can be found even when environmental quality is not the only differentiating factor between the products offered by different firms. Second, it suggests that this result does not depend critically on the multiplicity of equilibria inherent to our pure vertical differentiation model.

7 Related literature and conclusions

7.1 Related literature

Our observations depart from much of literature on the Porter Hypothesis on one key point: they describe a win-win result that rests on a demand-driven mechanism (consumer preferences for cleaner goods) rather than on any productivity gains or cost savings brought on by environmental innovation. In this section, we evaluate how the results of this modelling strategy accord with some of the key observations set forth in other papers on the subject.

First, the existing literature tends to suggest that a regulation-induced win-win situation in the context studied here is a rather exceptional result that only holds for a relatively narrow sub-set of parameter values. For example, in [22] it is argued that the Porter Hypothesis is likely to hold only in very special cases. Similarly, in [2] the possibility of attaining a Porter result is confined only to those parameters satisfying a very specific condition. Xepapadeas and de Zeeuw [24] are even more skeptical in this regard, since they claim that even if environmental regulation could mitigate the conflict between environmental quality and competitiveness, it would not be likely to yield a win-win situation.[16] Our paper supports this observation to the extent that we find a win-win result only in certain specific situations, although we do not treat it as a degenerate case. In particular, we find that a key factor conditioning the emergence of a win-win result can be expressed as a lower and an upper bound for the value of the high quality product in terms of the low quality and cost parameters.

A second observation to be extracted from the literature is that the Porter Hypothesis should be used cautiously as an argument for environmental regulation. In this respect, Simpson and Bradford [22] conclude that using more stringent environmental policies to motivate investment in order to strengthen the competitive advantage of domestic firms

[16] Moreover, [5] has proven that, if we relax certain assumptions, the results set forth in [24] will no longer hold, in such a way that the Porter hypothesis is always rejected.

"*may be a theoretical possibility, but it is extremely dubious as a practical advice*" (p. 296). Mohr [11] argues that an environmental policy that produces results consistent with the Porter Hypothesis is not necessarily optimal. On this issue, we arrive at a less standard conclusion. When the environmental policy increases firm profits, we suggest, it may well be that demand coverage increases along with the economic surplus of all consumers in the market. As a matter of fact, this is always the case when the fixed adoption cost represents the only extra expense associated with a firm's shift from a standard to an environmentally friendly variant of a given product. When this happens, a win-win environmental policy will unambiguously enhance efficiency. Nevertheless, some caution should still be exercised when giving policy recommendations, especially when adoption of the cleaner technology implies higher marginal costs.

7.2 Conclusions

In this paper, we have studied a duopoly model of vertical product differentiation in which firms simultaneously set the environmental quality (represented as a discrete variable) of a given product and then engage in price competition. The structure of this game can result in a classical prisoner's dilemma in that, at equilibrium, both firms produce the standard variant of the good but stand to benefit from a joint decision to produce the more environmentally friendly variant. In this context, the implementation of a "green" policy may enhance the environmental quality of the product while simultaneously increasing firms' private profits. This analysis gives rise to a win-win situation similar to that described by the Porter Hypothesis, one that rests on a pure (demand side) market mechanism rather than on any market failure such as externalities or informational asymmetries.

We have used a specific policy instrument to obtain these results: a penalty or lump-sum tax on firms producing the low quality variant of the product in question. This penalty can solve a coordination failure by inducing firms to move into a new profit-improving equilibrium. We also show that this coordination effect could be extended to encompass more complex forms of environmental regulation, such as effluent taxes.

Finally, we have stressed that environmental regulation can not only make firms more profitable, but it can also increase consumer surplus. This always occurs when producing the environmentally friendly product turns out to be more cost-efficient than producing the standard variant. Public intervention is clearly warranted in such cases, since such regulation would clearly benefit the environment, consumers and firms themselves.

References

[1] G.S. Amacher, E. Koskela, M. Ollikainen, Environmental Quality Competition and Eco-Labelling, J. Environ. Econom. Management 47 (2004) 284-306.

[2] S. Ambec, P. Barla, A Theoretical Foundation of the Porter Hypothesis, Econom. Lett. 75 (2002) 355-360.

[3] C. Crampes, A. Hollander, Duopoly and Quality Standards, Eur. Econom. Rev. 39 (1995) 71-82.

[4] G.S. Dastidar, On the Existence of Pure Strategy Bertrand Equilibrium, Econom. Theory 5 (1995) 19-32.

[5] G. Feichtinger, R.F. Hartl, P.M. Kort, V.M. Veliov, Environmental Policy, the Porter Hypothesis and the Composition of Capital: Effects of Learning and Technological Progress, J. Environ. Econom. Management 50 (2005) 434-446.

[6] D. Fullerton, G. E. Metcalf, Environmental controls, scarcity rents, and pre-existing distortions, J. Public Econom 80 (2001) 249-267.

[7] J. Gabszewick, J.F. Thisse, Price Competition, Quality, and Income Disparities, J. Econom. Theory 20 (1979) 340-359.

[8] M. Greaker, Spillovers in the development of new pollution abatement technology: A new look at the Porter-hypothesis, J. Environ. Econom. Management 52 (2006) 411-420.

[9] R. Hart, Growth, Environment and Innovation - a Model with Production Vintages and Environmentally Oriented Research, J. Environ. Econom. Management 48 (2004) 1078-1098.

[10] C. Lombardini-Riipinen, Optimal Tax Policy under Environmental Quality Competition, Environ. Resource Econ. 32 (2005) 317.336.

[11] R.D. Mohr, Technical Change, External Economies, and the Porter Hypothesis, J. Environ. Econom. Management 43 (2002) 158-168.

[12] R.D. Mohr, S. Saha, Distribution of Environmental Costs and Benefits, Additional Distortions, and the Porter Hypothesis, Mimeo: University of New Hampshire (2006) (http://pubpages.unh.edu/~rmohr/pubs.htm).

[13] K. Palmer, W.E. Oates, P.R. Portney, Tightening Environmental Standards: The Benefit-Cost or No-cost Paradigm, J. Econom. Perspect. 9 (1995) 119-132.

[14] D. Popp, Uncertain R&D and the Porter Hypothesis, Contrib Econ Anal. Policy 4 (2005), article 6.

[15] M. Porter, The Competitive Advantage of Nations, Free Press, New York, (1990).

[16] M. Porter, America's Green Strategy, Sci. Amer. 264 (1991) 96.

[17] M. Porter, C. van der Linde, Toward a new conception of the environment-competitiveness relationship, J. Econom. Perspect. 9 (1995) 97-118.

[18] P.R. Portney, Does Environmental Policy Conflict with Economic Growth?, Resources 115 (1994) 21-23.

[19] M. Rege, Strategic Policy and Environmental Quality: Helping the Domestic Industry to Provide Credible Information, Environ. Resource Econ. 15 (2000) 279-296.

[20] J. Rothfels, Environmental Policy under Product Differentiation and Asymmetric Costs: Does Leapfrogging Occur and Is It Worth It?, in L. Marsiliani, M. Rauscher, C. Withagen (Eds.), Environmental Economics and the International Economy, Kluwer Academic Publishers, 2002, pp. 99-122.

[21] A. Shaked, J. Sutton, Relaxing Price Competition through Product Differentiation, Rev. Econom. Stud. 49 (1982) 3-14.

[22] R.D. Simpson, R.L. Bradford III, Taxing Variable Cost: Environmental Regulation as Industrial Policy, J. Environ. Econom. Management 30 (1996) 282-300.

[23] J.F. Wasik, Green Marketing and Management: A Global Perspective. Cambridge, MA: Blackwell, 1996.

[24] A. Xepapadeas, A. de Zeeuw, Environmental Policy and Competitiveness: the Porther Hypothesis and the Composition of Capital, J. Environ. Econom. Management 37 (1999) 165-182.

A Appendix

A.1 Proof of Proposition 2

From the second inequality in (7), if follows that

$$\frac{c_H s_H^2 (2-\alpha)\alpha}{4(c_H+(2-\alpha)s_H)^2} - F_H > \frac{c_L s_L^2 (2-\alpha)\alpha}{4(c_L+(2-\alpha)s_L)^2} \Longleftrightarrow$$

$$s_H > \hat{s}_H \equiv \frac{c_H\sqrt{\frac{4F_H}{\alpha(2-\alpha)c_H}+\frac{c_L s_L^2}{(c_L+(2-\alpha)s_L)^2 c_H}}}{1-(2-\alpha)\sqrt{\frac{4F_H}{\alpha(2-\alpha)c_H}+\frac{c_L s_L^2}{(c_L+(2-\alpha)s_L)^2 c_H}}}.$$

The first inequality in (7) is $\Pi^*_{HL} < \Pi^*_{LL}$. Note that Π^*_{LL} does not depend on s_H whereas Π^*_{HL} is increasing in s_H and, moreover, $\lim_{s_H\to 0}\Pi^*_{HL} = 0$ and $\lim_{s_H\to\infty}\Pi^*_{HL} = \infty$.[17] This ensures that $\Pi^*_{HL} = \Pi^*_{LL}$ holds for a single value $\tilde{s}_H$ and, hence, $\Pi^*_{HL} < \Pi^*_{LL}$ holds if and only if $s_H < \tilde{s}_H$. This completes the proof. ■

A.2 Proof of Corollary 2

Let us define $B(s_H, s_L, c_H, c_L, \alpha) \equiv \Pi^*_{HL} - \Pi^*_{LL}$. A necessary requirement for Condition 2 in Corollary 1 to hold is that $B(s_H, s_L, c_H, c_L, \alpha) < 0$.

Assume first $\alpha = 1$. If we evaluate $B(s_H, s_L, c_H, c_L, \alpha)$ in $s_H = \frac{c_H}{c_L} s_L$ we have

$$B\left(\frac{c_H}{c_L}s_L, s_L, c_H, c_L, 1\right) > 0 \Longleftrightarrow$$

$$16c_H^2 s_L\left(s_L\left(\frac{c_H}{c_L}-1\right)+c_H\right)^3(c_L+s_L)^2 - 4c_L^3\left(\frac{c_H}{c_L}-1\right)s_L\left(s_L\left(\frac{c_H}{c_L}-1\right)+c_H\right)$$
$$-4c_H^2c_L^2(c_L+s_L)+3s_Lc_Hc_L^3 > 0.$$

[17] The fact that Π^*_{HL} is increasing in s_H is economically very intuitive but the proof is not so straightforward since the sign of the relevant derivative is not easy to check. A formal proof for this can be provided along the following lines: Assume that, if s_H increases, the firm producing with high quality uses a (suboptimal) adaptative strategy by fixing p_{HL} in such a way that the demand of the high-quality product remains unchanged. Then it follows that the firm producing the low-quality good will optimally react by increasing p_L so that p_H will also increase. This ensures higher profits for the high-quality firm. Since this is obtained with a suboptimal strategy, it is guaranteed that the optimal strategy will always provide higher profits and, hence, that Π_{HL} is increasing with in s_H. The details of this proof are available upon request.

Some tedious numerical computations allow us to check that for every (s_L, c_L, c_H) with $s_L > 0$ and $c_H > c_L > 0$ the above inequality holds. Using the same argument as in the proof of Proposition 2, this implies that, whenever $\frac{s_H}{c_H} > \frac{s_L}{c_L}$, it holds that $B(s_H, s_L, c_H, c_L, 1) > 0$, so $\Pi^*_{HL} > \Pi^*_{LL}$ and Condition 2 is not fulfilled if $\alpha = 1$. Since Π^*_{HL} does not depend on α and Π^*_{LL} is increasing in α for any $\alpha \leq 1$, it follows that Condition 2 is not fulfilled for any $\alpha \leq 1$. This completes the proof. ■

A.3 Proof of Lemma 2

Let $\bar{\theta}_{HH} = \frac{p_{HH}}{s_{HH}}$ and $\bar{\theta}_{LL} = \frac{p_{LL}}{s_L}$ denote the consumer who is indifferent between buying and not buying the good in the (s_H, s_H) and the (s_L, s_L) equilibrium, respectively. The fact that $\frac{s_H}{c_H} > \frac{s_L}{c_L}$, together with Lemma 1, ensures that $\bar{\theta}_{HH} < \bar{\theta}_{LL}$. Therefore, all the consumers located in the interval $\left(\bar{\theta}_{HH}, \bar{\theta}_{LL}\right]$ are strictly better off in the high quality equilibrium than in the low quality one. Now denote by $\Delta U(\theta) = \theta(s_H - s_L) - (c_H - c_L)$ the surplus differential of a consumer with taste parameter θ when shifting from (s_L, s_L) to (s_H, s_H). Since $s_H > s_L$, $\Delta U(\theta)$ is increasing in θ and, hence, all active consumers (those with $\theta > \bar{\theta}_{HH}$) also benefit from the quality shift. This completes the proof. ■

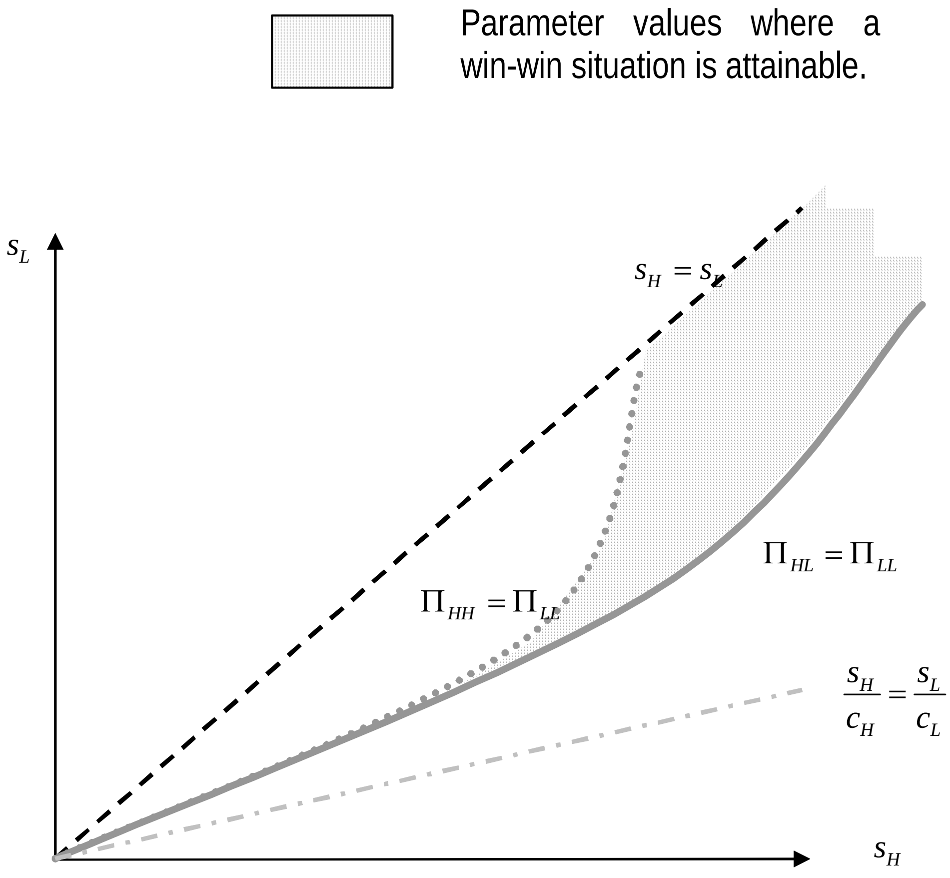

Figure 1: Example of win-win situations for $c_L = 100$ and $c_H = 500$ under marginal-cost pricing.