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Strategic Quality Competition and the Porter Hypothesis*

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Abstract

In this paper we provide a theoretical foundation for the Porter hypothesis in a context of quality competition. We use a duopoly model of vertical product differentiation where firms simultaneously choose the environmental quality of the good they produce (which can be either high or low) and, afterwards, engage in price competition. In this simple setting, we show that a Nash equilibrium of the game with low quality could be Pareto dominated by another strategy profile in which both firms produce the high environmental quality good. We then show how, in this case, the introduction of a penalty to any firm that produces the low environmental quality can result in an increase in both firms' profits. The impact of the policy on consumers depends on the effect of a quality shift on the cost structure of firms.

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1 Introduction

Conventional economic thinking suggests that more stringent environmental regulations always imply some private costs because they displace firms from their first best and make them be worse off. Porter [13], [14] challenged this view and claimed just the opposite. The main argument, which was further elaborated in [15], is that firms may not be aware of certain investment opportunities. Environmental regulation might make these opportunities apparent, trigger innovation and generate long run gains that could partially, or more than fully, offset the costs of complying with them. This claim is now widely known as the Porter hypothesis.

The Porter hypothesis received a skeptical response from economists on the grounds of standard economic theory (see, for instance, [11]). The notion that firms systematically overlook opportunities for making innovations or taking any other decision that would improve their results is difficult to reconcile with the neoclassical view of the firm as a rational profit-maximizing entity. To put it simply, if doing any change would benefit a firm, the firm will be willing to do it herself, and no policy should be needed.

Recently, other authors have reported some mechanisms through which a Porter result may emerge. These explanations have in common the existence of some market failure that offers a field for environmental regulation to benefit firms, although this failure may be at different levels corresponding to different interpretations of the Porter hypothesis. In an economic growth framework, Hart [8] shows that an environmental policy could foster R&D activities and increase growth. Simpson and Bradford [18] show in an international trade model that a strengthening of regulation may result in a shift of profits from foreign to domestic firms because of the presence of international externalities. There are some papers that report intra-firm mechanisms through which environmental regulation can induce the adoption of profit-enhancing innovations. In this line, Xepapadeas and de Zeeuw [20] conclude that a more stringent environmental regulation can have positive (downsizing and modernization) effects on firms, Popp [12] shows that firms may decide to undertake uncertain R&D projects that turn out to be ex-post profitable, only when regulation is in place, and in [2] a win-win situation arises as the environmental policy alleviates an informational problem between the firm and the manager. Finally, Mohr [10] and Greaker [7] present inter-firm mechanisms through which a strict environmental policy induces firms to invest in new pollution abatement techniques and may benefit competitiveness.

In this paper we report an additional reason why a win-win situation may emerge in a context of vertical product differentiation. The economic rationale behind our findings is the following: firms sometimes must decide whether to stick to a product with a low environmental quality or jump to produce a high environmental quality product. High quality products typically entail higher production costs, although consumers reward this effort to some extent by being willing to pay a higher price for a cleaner product (see, for instance, [19]). In this framework, a firm could be reluctant to shift to produce high quality goods as this may put her at a disadvantage when competing in prices. The reason is that low quality providers could benefit by offering cheaper products, serving a large fraction of demand and, thus, making the introduction of environmentally friendly products in the market not profitable enough. Nevertheless, if all firms shifted to produce high quality products, they could jointly benefit from the higher willingness to pay of consumers without the risk of being exploited by their competitors. In game theory this situation corresponds to a prisoner's dilemma in which the Nash equilibrium of the game is Pareto dominated by a different strategy profile that, however, is not an equilibrium because all the agents would have individual incentives to deviate from it. In our framework, environmental regulation can provide a win-win situation by inducing all the firms to shift to environmentally friendly products and make both the environment and firms be better off. The closest papers to ours in the literature are [10] [7]. Although different in nature, their mechanisms to sustain a Porter result also rest on a coordination failure as individual firm incentives to adopt new technologies do not match with the collective interest of the industry.

We derive our results within a model of vertical product differentiation where two firms have to simultaneously choose the environmental quality of the good they produce (which can be either high or low) and, afterwards, engage in price competition. The model is a standard model of vertical product differentiation, in the line of the seminal papers by Gabszewick and Thise [6] or Shaked and Sutton [17],[1] except for the fact that we restrict environmental quality to be discrete - rather than a continuous variable - so firms can only choose between a finite number of options to produce their good. This could be a rather natural and realistic modeling strategy in many contexts, since firms usually make discrete decisions related to the environmental quality of their products: using conventional paper or recycled paper, using fossil fuels or renewable energy, etc. The possibility to attain a win-win situation relies heavily on the fact that firms do not have full capacity to fine-tune their quality choices to those of their competitors, as only a discrete set of alternatives is available.

In this framework, we show that it is possible to find environmental policies that may simultaneously improve environmental quality and increase the profit of firms. We also investigate the effect of the intensity in price competition (when quality is symmetric) on the scope for the existence of a Porter result and we find that it crucially depends on how the improvement

[1] This kind of models has been recently applied to the study of environmental quality. See, for instance, [1] and [9].

in the environmental quality affects the cost structure of firms. When the production of the environmentally friendly product entails a fixed cost of technology adoption we find that less price competition undoubtedly enlarges the set of parameters compatible with a Porter result. However no clear prediction can be drawn when the shift to the clean technology entails higher marginal costs to the firm. Finally, we explore the impact of an environmental policy on market coverage and consumer surplus and come up with the conclusion that, again, the effects strongly depend on the cost structure of the firms. If the shift from low to high environmental quality entails higher marginal costs, consumers will always be worse off as the price increment willl offset the gain from enjoying a higher quality. On the other hand, if marginal costs remain constant and the shift only implies a fixed cost of technology adoption, consumers will always benefit from any policy that forces firms to raise quality.

The rest of the paper is structured as follows. In section 2 we present the model. In Section 3 we solve for equilibrium prices and qualities without environmental regulation. In Section 4 we analyze under which conditions it is possible to obtain a prisoner's dilemma, which opens a scope for the environmental policy to provide a win-win situation. In Section 5 we address the effects of environmental regulation on consumer surplus. Section 6 offers some discussion about the results and their relation with those in previous articles. All of the proofs are in the Appendix.

2 The Model

We consider a duopoly model of vertical product differentiation under full information.[2] Both firms produce a good that can be vertically differentiated in environmental quality. Each firm decides the level of environmental quality s_i of its own good, which can be high ($i = H$) or low ($i = L$). Production costs are given by $C_i(x) = F_i + c_i x^2$ ($i = H, L$), where x represents the output level and F_i, $c_i > 0$ are cost-specific parameters.[3] We assume $F_H \geq F_L$ and $c_H \geq c_L$ to represent the fact that producing a specific amount of the high environmental variant of the product may be more costly than producing the same amount of the low environmental one in two different senses: first, $F_H \geq F_L$, meaning that shifting to the high quality product may

[2] The assumption of full information is usual in models of vertical product differentiation. Despite environmental quality can be something difficult to observe directly by consumers, the introduction, for instance, of eco-labelling schemes, may help to mitigate this potential asymmetry of information between consumers and producers.

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

entail a higher fixed cost (that we take as sunk in the production stage), where $F_H - F_L$ can be interpreted as a fixed cost of technology adoption; second, $c_H \geq c_L$, implying that, for a given amount of output, the marginal cost associated to higher quality products may be higher than that of low quality products (due, for instance, to the need of more demanding security standards, more expensive materials, etc.). In Sections 4 and 5 we sort out the implications of these two possibilities.

Let p_i be the price of product with quality s_i, then the profit function of any firm producing x units of output with quality s_i is $\Pi_i = p_i x - C_i(x)$, $i = H, L$.

Finally, there is a continuum of consumers whose willingness to pay for environmental quality is measured by the parameter θ, which is uniformly distributed over the interval $[\underline{\theta}, \bar{\theta}]$. For simplicity, we assume throughout the paper $\underline{\theta} = 0$, $\bar{\theta} = 1$ and the number of consumers is normalized to unity. Each consumer either buys one unit of the commodity or nothing. The indirect utility (or consumer surplus) of a consumer of type θ is given by $U_i = \theta s_i - p_i$ if he buys a good of environmental quality s_i at price p_i and zero if he does not buy any good.[4]

3 Price and Quality Competition

We now analyze our two-stage game. In the *first stage*, firms simultaneously choose the level of environmental quality for their goods. Depending on firms' decisions, the market may have three different configurations: (i) both firms produce the low quality variant of the good, (ii) both firms produce the high quality variant or (iii) one firm produces the low quality variant and the other firm the high variant one. The two first cases imply homogeneous product, while the third results in a market with vertically differentiated products. In the *second stage*, firms compete in prices à la Bertrand.

3.1 Preliminaries

We start by computing the demand functions for each quality mix. Since quality is a discrete choice for firms, we need to consider two possibilities: symmetric and asymmetric quality. Denote as p_{ij} and x_{ij} the price set and the demand faced by a firm producing with quality s_i when her rival produces with quality s_j (i, $j = L, H$). X_i represents the market demand of the good with quality s_i.

Assume, first, that both firms offer the same environmental quality s_i. In this scenario consumers have two alternatives: either to buy one unit of good or not buying at all. For a

[4] The assumption $\underline{\theta} = 0$ ensures that there is not full market coverage, i.e., for any positive price, there are always some consumers who prefer not to purchase any good.

consumer of type θ it is optimal to purchase one unit of the product if and only if $\theta s_i - P_i \geq 0$, P_i being the lowest price available in the market. Hence, the market demand of a good with environmental quality s_i is given by the mass of consumers with $\theta \geq \frac{P_i}{s_i}$, i.e.,

$$X_i = \max\left\{1 - \frac{P_i}{s_i}, 0\right\}, \qquad i = H, L.$$

The demand function faced by firm a if she sets price p_{ii}^a and her competitor b sets price p_{ii}^b takes the form

$$x_{ii}^a\left(p_{ii}^a, p_{ii}^b\right) = \begin{cases} \max\left\{1 - \frac{p_{ii}^a}{s_i}, 0\right\} & \text{if } p_{ii}^a < p_{ii}^b \\ \frac{\max\left\{1 - \frac{p_{ii}^a}{s_i}, 0\right\}}{2} & \text{if } p_{ii}^a = p_{ii}^b \\ 0 & \text{if } p_{ii}^a > p_{ii}^b. \end{cases}$$

Secondly, consider the case where firms produce with different environmental qualities. In this case the options for consumers are: (i) buying one unit of the high environmental variant of the good, (ii) buying one unit of the low environmental variant or (iii) not buying at all. We define the critical willingness to pay $\bar{\theta}_H$ at which the consumer is indifferent between buying the high and low quality good, and the critical willingness to pay $\bar{\theta}_L$ at which the consumer is indifferent between purchasing the low quality good or not buying at all. A consumer with taste parameter θ prefers s_H to s_L if and only if $\theta s_H - p_{HL} \geq \theta s_L - p_{LH}$, from which we obtain $\bar{\theta}_H = \frac{p_{HL} - p_{LH}}{s_H - s_L}$. Analogously $\bar{\theta}_L$ is given by the solution to the indifference relation $\theta s_L - p_{LH} = 0$, so that $\bar{\theta}_L = \frac{p_{LH}}{s_L}$.

Therefore, as θ is uniformly distributed on $[0, 1]$, the demand for the high quality good is[5]

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

and the demand for the low-quality good is:

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

3.2 Price Competition Game

We solve the game backwards starting from the second stage, the price game. Firms choose prices subject to their previous choices for environmental quality.

When both firms offer the same environmental quality s_i, the market structure is given by two symmetric firms competing in prices and selling a homogeneous good. Let $\Pi_{ii}^a\left(p_{ii}^a, p_{ii}^b\right) \equiv$

[5]We are implicitly assuming that the fixed adoption costs are sunk in the price competition stage and that both firms are active, i.e $x_{HL} > 0$ 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 will see later this always holds in equilibrium.

$p_{ii}^a x_{ii}^a - C_i\left(x_{ii}^a\left(p_{ii}^a, p_{ii}^b\right)\right)$ denote the profit of firm a in the symmetric quality game when she sets price p_{ii}^a and her competitor sets price p_{ii}^b.

The characterization of the equilibrium price in the symmetric case departs from the classic Bertrand paradox with price equal to marginal cost (which is the unique Nash equilibrium when firms have constant marginal costs), due to the existence of strictly convex costs. In fact, Dastidar [4] proved that in a Bertrand model with symmetric firms and strictly convex costs the Nash equilibria are necessarily non-unique. 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 $\underline{p_i}$ and $\bar{p}_i$ are defined by the following conditions:[6]

$$\begin{aligned}
\Pi_{ii}^a\left(p_{ii}^a = \underline{p_i}, p_{ii}^b = \underline{p_i}\right) &= -F_i \\
\Pi_{ii}^a\left(p_{ii}^a = \bar{p}_i, p_{ii}^b = \bar{p}_i\right) &= \bar{p}_i\, X_i\left(\bar{p}_i\right) - C_i\left(X_i\left(\bar{p}_i\right)\right).
\end{aligned}$$

In words, $\underline{p_i}$ is the lowest price compatible with an equilibrium and it is defined as the price that equals average variable costs, making firms indifferent between producing at $\underline{p_i}$ and not producing. In turn, $\bar{p}_i$ is the highest price compatible with a Nash equilibrium and it is defined as the price such that every firm is indifferent between setting the equilibrium price $\bar{p}_i$ (and hence splitting the demand evenly) and cutting marginally her price in order to exclude her rival and serve the whole demand.

For each game, the location of the equilibrium price in the interval $\left[\underline{p_i},\ \bar{p}_i\right]$ can be interpreted as the degree of strength of price competition. The situation with $p_{ii}^* = \underline{p_i}$ can be seen as the one with the toughest competition and $p_{ii}^* = \bar{p}_i$ as the one with the mildest competition. Some straightforward computations show that, depending on the degree of price competition, the price $(p_{ii}^{a*} = p_{ii}^{b*} = p_{ii}^*)$, the demand faced by each firm $(x_{ii}^{a*} = x_{ii}^{b*} = x_{ii}^*)$ and firm profits $(\Pi_{ii}^{a*} = \Pi_{ii}^{b*} = \Pi_{ii}^*)$ in equilibrium can be parameterized in the following way:

$$p_{ii}^* = \frac{c_i s_i}{c_i + (2-\alpha)\, s_i}, \qquad x_{ii}^* = \frac{s_i\,(2-\alpha)}{2\left(c_i + (2-\alpha)\, s_i\right)}, \qquad i = H, L, \tag{1}$$

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

where α represents the (inverse of the) degree of strength in the price competition and it 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 of price equal to marginal cost. However, it is worth mentioning that it is possible for the joint-profit maximizing

[6] Since the game is symmetric, so will be the equilibrium. In order to simplify the notation, from now on we will drop the superscripts a and b when there is no ambiguity.

price (i.e. the collusive price) to fall within this range of Bertrand equilibrium prices. To rule out this economically unappealing case in which the Bertrand equilibrium price is higher than the collusive price, we restrict α to be smaller or equal than $\hat{\alpha} \equiv \frac{2s_i+c_i}{s_i+c_i}$. Hence, in what follows we will consider equilibrium prices determined by the range $\alpha \in \left[0, \min\left\{\frac{4}{3}, \hat{\alpha}\right\}\right]$.[7] Moreover, we assume that the degree of price competition is the same for both quality choices. This is done to reduce the casuistic of the cases under study.

When firms offer different environmental qualities and compete in prices, they choose p_{HL} and p_{LH} so as to maximize profits:

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

and

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

>From the first order conditions we obtain the following reaction functions:

$$\begin{array}{l} p_{HL}\left(p_{LH}\right) = \frac{(s_H - s_L)^2 + p_{LH}(s_H - s_L) + 2p_{LH}c_H + 2c_H(s_H - s_L)}{2(s_H - s_L) + 2c_H} \\ p_{LH}\left(p_{HL}\right) = \frac{s_L^2(s_H - s_L)p_{HL} + 2c_L s_H s_L p_{HL}}{2s_L s_H(s_H - s_L) + 2c_L s_H^2}. \end{array}$$

The solution of the system of equations defined by $p_{HL}(p_{LH})$ and $p_{LH}(p_{HL})$ gives the equilibrium prices and, from them, equilibrium quantities and profits are directly derived.

For the firm that produces the low quality variant of the product:

$$\begin{aligned} p_{LH}^* &= \frac{s_L\left(s_L\left(s_H - s_L\right) + 2c_L s_H\right)\left(s_H - s_L + 2c_H\right)}{\Lambda}, \\ x_{LH}^* &= \frac{s_L s_H\left(s_H - s_L + 2c_H\right)}{\Lambda}, \\ \Pi_{LH}^* &= \left(\frac{s_L\left(s_H - s_L + 2c_H\right)}{\Lambda}\right)^2 s_H\left(s_L\left(s_H - s_L\right) + c_L s_H\right) - F_L. \end{aligned}$$

For the firm that produces the 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.

[7] It is easy to show that the collusive price is given by $p_i^{\text{col}} = \frac{s_i(c_i+s_i)}{2s_i+c_i}$, and $p_{ii}^* \leq p_i^{\text{col}}$ if and only if $\alpha \leq \hat{\alpha}$.

3.3 Quality Choice Game

In the first stage, duopolists decide the environmental quality of the good they produce: s_L or s_H taking into account the consequences of their decision for the second stage. We can summarize the quality choice decision of firms as a simultaneous game in normal form as follows:

Firm 2

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

(3)

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

4 Environmental Regulation and the Porter Hypothesis

The purpose of this section is to answer the following questions: is it possible that both firms can be unambiguously better off as a consequence of an environmental policy?, and if so, which are the economic driving forces for such a result to arise?

Assume that the government wants to promote the use of an environmentally better technology, so that he implements some environmental policy oriented towards discouraging the production of the low environmental variant of the good. To simplify the exposition we focus on a simple instrument such as a penalty or lump-sum tax (T) imposed on those firms that produce the low environmental variant of the good.

To some extent, the results turn out to depend on whether the shift from low to high quality entails a fixed cost of technology adoption or an increase in marginal costs of production. These possibilities are studied separately. We start with two examples and some general results and then move to a thorough analysis of both possibilities.

4.1 Examples and General Results

Example 1 *(Differences in marginal costs)*

Assume 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

Firm 1		s_H	s_L
	s_H	$(17.58,\ 17.58)$	$(9.95,\ 27.79)$
	s_L	$(27.79,\ 9.95)$	$(13.04,\ 13.04)$

Importantly, note that this game has the structure of a typical prisoner's dilemma: the unique Nash equilibrium of this game is (s_L, s_L), which is inefficient from the point of view of firms, as both firms would be better off if they coordinated to play (s_H, s_H). However, this latter outcome is not a Nash equilibrium because each firm has incentives to deviate from it.

Assume now that the government imposes a fix penalty T on those firms that produce the low environmental variant of the product. The new payoff matrix of the game is as follows:

Firm 2

Firm 1		s_H	s_L
	s_H	$(17.58,\ 17.58)$	$(9.95,\ 27.79 - T)$
	s_L	$(27.79 - T,\ 9.95)$	$(13.04 - T,\ 13.04 - T)$

The payoff matrix of this second game shows that the penalty reduces the payoffs of firms in some situations, and it does not increase the payoffs of the firms in any case. At a first sight, one may think that this policy can never benefit firms. Nevertheless, it is immediate to check that, for any value $T > 10.21$, the Nash equilibrium of the quality game changes to (s_H, s_H). If we compare the equilibrium outcome before and after the environmental regulation, we conclude that both firms are better off when the penalty is imposed.

The economic intuition behind this result is the following: in the original quality choice game, both firms would benefit if they moved jointly from s_L to s_H. Yet, this does not happen because the firm that decides to produce the high quality variant of the product would suffer from the opportunistic behavior of her competitor: by sticking to the low quality product, it is possible to produce with a lower cost, charge a lower price and, hence, keep a large share of the market. Environmental regulation eliminates the scope for this opportunistic behavior and, hence, solves the coordination failure.

Example 2 *(Fixed cost of technology adoption)*

Assume now the following parameter configuration and the associated payoff matrix for the quality-choice game:

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

Firm 2

Firm 1		s_H	s_L
	s_H	$(6.48, 6.48)$	$(6.15,\ 5.42)$
	s_L	$(5.42,\ 6.15)$	$(6.24,\ 6.24)$

The structure of this game is not consistent with a prisoner's dilemma since both (s_L, s_L) and (s_H, s_H) are Nash equilibria. Nevertheless, the fact that the latter dominates the former from the point of view of firms gives some scope for a win-win situation to arise: by discouraging low quality, environmental policy solves the coordination failure, eliminates the multiplicity of equilibria and ensures that the "good" 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).

We move now to study more formally the conditions under which a microfoundation for the Porter hypothesis can be obtained. For a given penalty T, the regulated quality choice game in normal form is:

Firm 2

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

(4)

Let us formalize what does it mean to achieve a win-win situation in this framework:

Definition 1 *We say that an environmental policy (characterized by a penalty $T > 0$ imposed on those firms that produce the low environmental variant of the product) yields a* ***win-win situation*** *if the (unique) Nash equilibrium of the regulated quality choice game (4) results in higher payoffs for both firms than those of a (not necessarily unique) Nash equilibrium of the unregulated game (3).*

The definition of a win-win situation is, in principle, compatible with any equilibrium configuration, but intuition suggests that this result can only occur when the equilibrium of the game shifts from (s_L, s_L) without environmental regulation to (s_H, s_H) when the policy is implemented, as shown in the previous examples. The following proposition confirms this intuition.

Proposition 1 ***(Necessary Condition)*** *Environmental regulation can yield a* ***win-win situation*** *only if (s_L, s_L) is a Nash equilibrium of the quality choice game (3) and (s_H, s_H) is the unique Nash equilibrium of the regulated quality choice game (4).*

>From Proposition 1 it is immediate to obtain the following result, which provides us with the necessary and sufficient conditions for the environmental regulation to generate a win-win situation.

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

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

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

Condition (i) requires that (s_H, s_H) is the only Nash equilibrium of the regulated quality choice game. Condition (ii) requires that, on the one hand, there is an equilibrium of the unregulated game such that both firms choose to provide the low environmental quality and, on the other hand, both firms would be better off if they simultaneously produced the high, rather than low, environmental quality.

It is straightforward to see that, provided the value of T is sufficiently high, condition (i) holds. The fulfillment of condition (ii) is analyzed with some detail in the two cases displayed below:

4.2 Fixed Cost of Technology Adoption ($F_H > F_L$)

Assume first that $c_H = c_L \equiv c$, so that the only difference between producing low and high quality is that the latter entails a higher fixed cost (F_H) than the former (F_L). This can be interpreted as a situation where there is a fixed cost of technology adoption equal to $F \equiv F_H - F_L$.

As discussed above, the fulfillment of condition (i) in Corollary 1 is guaranteed if T is high enough, so that the crucial condition to get a win-win situation is $\Pi^*_{HL} < \Pi^*_{LL} < \Pi^*_{HH}$. In this setting, the condition for a Porter result to emerge can be expressed as

$$F \in \left(\underline{F}, \overline{F}\right), \qquad \text{with } \underline{F} \equiv \Pi^{*\prime}_{HL} - \Pi^{*\prime}_{LL},\ \overline{F} \equiv \Pi^{*\prime}_{HH} - \Pi^{*\prime}_{LL}, \tag{5}$$

where $\Pi^{*\prime}_{ij} \equiv \Pi^*_{ij} + F_i$, $(i, j = L, H)$ denotes the profit of a firm producing with quality s_i against a competitor with quality s_j, gross of fixed costs.

Condition (5) defines a feasible range for the values of the adoption cost F that are compatible with a win-win situation. For this range to be non-empty, it is needed that $\Pi^{*\prime}_{HL} < \Pi^{*\prime}_{HH}$. Starting from here we obtain the following results:

Proposition 2 *Assume $F_H > F_L$, $c_H = c_L \equiv c$ and $\alpha \in \left(0, \min\left\{\frac{4}{3}, \hat{\alpha}\right\}\right]$. A win-win situation can only occur if $\alpha \in \left(1, \min\left\{\frac{4}{3}, \hat{\alpha}\right\}\right]$.*

Corollary 2 *Assume $F_H > F_L$, $c_H = c_L \equiv c$ and $\alpha \in \left(0, \min\left\{\frac{4}{3}, \hat{\alpha}\right\}\right]$. An increase in α enlarges the set of parameters compatible with a win-win result.*

In this framework with a fixed cost of technology adoption the degree of price competition is the key variable for the emergence of a Porter result. First, from Proposition 2 we see that a win-win situation is possible only when the intensity in price competition is low enough. Moreover, Corollary 2 reinforces this result by showing that (provided $\alpha \in \left(1, \min\left\{\frac{4}{3}, \hat{\alpha}\right\}\right]$) the scope for a win-win situation undoubtedly widens as the intensity in price competition decreases.

The reason is the combination of two effects: on the one hand, the lower the degree of price competition the less appealing is for any firm to switch individually from the (s_L, s_L) equilibrium to one with asymmetric qualities. At the same time, the alternative of both firms coordinating in (s_H, s_H) becomes more attractive as α increases, since the potential gains are larger.

4.3 Differences in Marginal Costs ($c_H > c_L$)

Assume now that the high quality product conveys higher marginal costs ($c_H > c_L$). For simplicity, assume also $F_H = F_L = 0$.

Using the analytical expressions for the equilibrium profits computed in Subsection 3.2, we can rewrite condition (ii) in Corollary 1 as follows:

$$\left(\frac{2s_H\left(s_L\left(s_H - s_L\right) + c_L s_H\right)}{\Lambda}\right)^2 \left(s_H - s_L + c_H\right) < \frac{c_L s_L^2\left(2-\alpha\right)\alpha}{4\left(c_L + \left(2-\alpha\right)s_L\right)^2} < \frac{c_H s_H^2\left(2-\alpha\right)\alpha}{4\left(c_H + \left(2-\alpha\right)s_H\right)^2} \tag{6}$$

In Proposition 3 we show that, for any given value of s_L, c_H and c_L, this condition can be expressed as a lower and upper bound for s_H.

Proposition 3 *Assume $F_H = F_L = 0$ and $c_H > c_L$. For any $(s_L, c_H, c_L, \alpha) \in \mathbb{R}^4_{++}$ there exist two thresholds $\hat{s}_H$ and $\tilde{s}_H$ such that there are environmental regulations (values of T) that yield a win-win situation if and only if $\hat{s}_H < s_H < \tilde{s}_H$, with $\hat{s}_H \equiv \frac{c_H}{\sqrt{\frac{c_H}{c_L}\left(\frac{c_L}{s_L}+2-\alpha\right)}-(2-\alpha)}$ and $\tilde{s}_H$ being implicitly determined by the condition $\Pi^*_{HL_{|\tilde{s}_H}} = \Pi^*_{LL}$, where $\Pi^*_{HL_{|\tilde{s}_H}}$ denotes the value of Π^*_{HL} when $s_H = \tilde{s}_H$.*

Proposition 3 implies, first, that the quality of the environmentally friendly product has to be sufficiently high, so that firms' profits are higher when both of them decide to produce the high quality than when they both choose the low one. Secondly, the quality of the high environmental variant of the product should not be too high because, otherwise, firms would choose always this level of quality even in the absence of any environmental regulation.

Figure 1 illustrates, for the particular parameter configuration of Example 1, the region where environmental regulation can sustain a win-win result:

[Insert Figure 1]

Proposition 3 states that a win-win situation can only emerge when s_H takes an intermediate value, neither too high nor too low. Nevertheless, this proposition does not provide any intuition concerning what "intermediate" means and, in particular, about the relationship between low and high environmental qualities. The following corollary provides some additional information about this issue and, specifically, about what "not too high" means in the Bertrand reference case of marginal cost pricing.

Corollary 3 *Assume $F_H = F_L = 0$, $c_H > c_L$ and $\alpha = 1$. 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 $\frac{s_H}{c_H} \geq \frac{s_L}{c_L}$ condition (ii) in Corollary 1 never holds since $\Pi^*_{HL} > \Pi^*_{LL}$.*

The intuition behind this result is the following. A necessary condition for a win-win situation is that in the unregulated game no firm has individual incentives to differentiate her product and shift to the high quality. If one firm differentiated her product, this would alleviate price competition among firms. If despite this positive effect firms stick to produce the low environmental quality of the good, the reason has to be that the increase in costs from shifting to high quality outweighs any gain from the softer market competition. Hence, firms can only benefit from a more stringent environmental regulation if the cost of producing the environmentally friendly product is sufficiently high relative to that of the low quality alternative ($c_H > \frac{s_H}{s_L} c_L$).

As for the case with a fixed cost of technology adoption we are also interested in analyzing to what extent the scope for a win-win situation depends on the degree of strength of the price competition as measured by α.

Let us focus first on the extreme case of maximum price competition ($\alpha = 0$). In such a situation the possibility to achieve a win-win situation is ruled out completely, since $\Pi^*_{LL} = \Pi^*_{HH} = 0$. At equilibrium, firms never choose the same quality for their products as this would imply facing a price war that would exhaust completely their profits.

If we depart from this extreme case and consider equilibrium configurations where firms make positive profits (i.e., $\alpha > 0$), the effect of α can be checked by studying its impact on the key condition $\Pi^*_{HL} < \Pi^*_{LL} < \Pi^*_{HH}$ (see Corollary 1). Despite we are not able to obtain a closed result, we can illustrate the main insights by taking as reference the parameter values in

Example 1. In this case, for $\alpha = 1.15$ it is easy to see that a Porter result can be sustained for any $s_H \in (261.686,\ 344.350)$. For a larger α, for instance $\alpha = 1.25$, a Porter result can be sustained for any $s_H \in (279.786,\ 359.169)$. This means that when the production of an environmentally friendly product entails higher marginal costs a milder degree of price competition does not necessarily widen the set of parameters compatible with a win-win result.

This is in contrast with the result of the previous subsection where less price competition undoubtedly enlarged the scope for the existence of a win-win result. Here two contradictory effects are in place. On the one hand, as before, a higher α softens the constraint $\Pi^*_{LL} > \Pi^*_{HL}$. On the other hand, however, it can be the case (as illustrated in the example above) that an increase in α makes the constraint $\Pi^*_{HH} > \Pi^*_{LL}$ more demanding. The reason lies on the differences in the costs of production. When the prevailing quality-mix is (s_L, s_L) firms produce with a smaller cost parameter (c_L) than when they choose (s_H, s_H) and this lower cost intensifies price competition. As a result, a reduction in price competition has a stronger positive effect on profits when firms produce the low environmental quality. This reduces the wedge between Π^*_{HH} and Π^*_{LL} and makes condition $\Pi^*_{HH} > \Pi^*_{LL}$ more difficult to hold.

Sticking again to Example 1 let us compute the degrees of price competition compatible with a win-win situation. The quality choice game is represented by the following payoff matrix:

Firm 2

		s_H	s_L
Firm 1	s_H	$\left(\frac{11250000\alpha(2-\alpha)}{(1100-300\alpha)^2},\ \frac{11250000\alpha(2-\alpha)}{(1100-300\alpha)^2}\right)$	$(9.95,\ 27.79)$
	s_L	$(27.79,\ 9.95)$	$\left(\frac{1690\,000\alpha(2-\alpha)}{(620-260\alpha)^2},\ \frac{1690\,000\alpha(2-\alpha)}{(620-260\alpha)^2}\right)$

It is easy to check that $\Pi^*_{LL} < \Pi^*_{HH}$ holds for any $\alpha \in \left(0, \frac{4}{3}\right]$,[8] so that the only relevant condition is $\Pi^*_{HL} < \Pi^*_{LL}$. This condition, in turn, holds if and only if $\alpha \in \left(0.824, \frac{4}{3}\right]$, i.e., if the degree of intensity in price competition is not too high.

5 Market Coverage and Consumer Surplus

This section focuses on the impact of environmental regulation on demand coverage and consumer surplus, focusing on those environmental regulations that benefit firms. This issue is far from being trivial: although consumers have a preference for environmental quality, consuming the environmentally friendly product may be more expensive.[9]

[8] For this parameter configuration it holds that $\hat{\alpha} > \frac{4}{3}$.

[9] For example, Crampes and Hollander [3] show, in a model with continuous quality, that the effect of a minimum quality standard on consumers' welfare depends on the quality response of the high quality producer.

It turns out that the effect on market coverage and consumer surplus strongly depends on whether the cost differential between low and high environmental quality takes the form of higher marginal costs or a fixed cost of technology adoption, as shown in the following propositions.

Consider first the case of fixed adoption costs. It can be shown that:

Proposition 4 *Assume $F_H > F_L$ and $c_H = c_L \equiv c$. A shift from (s_L, s_L) to (s_H, s_H) causes that (1) more demand is covered and (2) the surplus of every consumer in the market increases.*

On the contrary, in the case of higher marginal costs, we can show that, for the Bertrand reference case of marginal-cost pricing, the following result holds:

Proposition 5 *Assume $F_H = F_L$, $c_H > c_L$ and $\alpha = 1$. Any environmental regulation that generates a win-win situation has the following implications: (1) less demand is covered and (2) the surplus of every consumer in the market decreases.*

These propositions introduce a caveat in the utilization of the Porter hypothesis as a support for environmental regulation in this context: whenever an environmental policy simultaneously benefits the environment and the firms in the market, the effects on demand coverage and consumer surplus may be positive or negative depending on how is the cost differential between low and high quality.

Proposition 4 states that, when low and high quality have the same marginal costs and the quality shift just implies a fixed adoption cost, consumers will always benefit when moving from a (s_L, s_L) equilibrium to a (s_H, s_H) equilibrium. Note that this 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 provided, even if this change does not profit firms. This is due to the fact that equilibrium prices only depend on marginal costs and not on fixed cost and, as a consequence, when sifting from s_L to s_H consumers face a product with the same marginal cost and a higher quality, which will unambiguously make them be better off.

On the other hand, Proposition 5 shows that, when shifting to high quality entails a higher marginal cost, an environmental policy that simultaneously benefits firms and the environment will always reduce the economic surplus of all the consumers in the market in the reference case of marginal cost pricing. The intuition for this result is the following. An environmental policy can benefit firms only in those cases in which the advantage of the high quality product over the low one is relatively narrow (see Corollary 3). In those situations, market interaction makes firms be reluctant to adopt the environmentally friendly good and the environmental policy solves this problem by giving firms the necessary push forward. However, when the advantage of the environmentally friendly product is not very large, the increase in quality does not compensate the larger price paid by consumers, so that consumers end up having a lower surplus.

6 Relationship with the previous literature and concluding remarks

6.1 Relationship with the previous literature

The results in this paper are very consistent with two central observations shared by previous papers in the literature related to the Porter hypothesis. Firstly, the possibility that an environmental regulation generates a win-win situation is shown to be a rather exceptional result that only holds for a relatively narrow sub-set of parameter values. For example, in [18] it is argued that the Porter hypothesis is likely to hold only in very special cases. Similarly, in [2] the possibility to attain a Porter result is confined only to those parameters satisfying a very specific condition. Xepapadeas and de Zeeuw [20] are even more skeptical as they claim that even if environmental policy could relax the conflict between environmental quality and competitiveness, it is not likely to provide win-win situations.[10] Our results show that, although a win-win result is not a degenerate case, it only appears in specific situations. In particular, if the marginal cost of producing high quality is larger than that of producing low quality, then a win-win result requires that the high environmental quality should be neither too high nor too low for given values of the low quality and the cost parameters. If marginal cost is the same for both variants but the high quality entails an adoption cost, then it is necessary that the degree of price competition is not too high and the technology adoption cost takes an intermediate value.

The second observation is that the Porter hypothesis should be used cautiously as an argument to promote environmental regulation. In this respect, Simpson and Bradford [18] conclude that using more stringent environmental policies to motivate investment in order to increase domestic industrial advantage “may be a theoretical possibility, but it is extremely dubious as practical advice” (p. 296). Mohr [10] argues that an environmental policy that produces results consistent with the Porter hypothesis is not necessarily optimal. Regarding this issue, we have shown that when an environmental policy increases firm profits, it will not always make consumers be better off in terms of their economic surplus, and that this effect strongly depends on how is the cost differential when moving from low to high quality. Thus, our results concur

[10] Moreover, in [5] it is proven that, after relaxing some assumptions, the results in [20] do not hold any more, in such a way that the Porter hypothesis is always rejected.

with the previous literature in suggesting that the fulfillment of the Porter hypothesis is neither a necessary nor a sufficient condition to unambiguously justify any specific policy in economic terms.

6.2 Concluding remarks

We have studied a duopoly model of vertical product differentiation where firms simultaneously choose the environmental quality of the good they produce as a discrete variable, and afterwards, engage in price competition. We have shown that the structure of this game can result in a classical prisoner's dilemma in the sense that, at equilibrium, both firms produce the low quality variant of the good, while they could benefit it they moved together to produce the environmentally friendly product. In this context, an environmental policy may enhance environmental quality while at the same time it increases firms' private benefits.

To derive our results we have focused on a specific policy instrument: a penalty (which can also be interpreted as a lump-sum tax) on those firms that produce low quality products. This penalty can solve a coordination failure by moving firms to a new profit-improving equilibrium. This coordination effect could be extended to encompass other forms of regulation. The most straight-ahead procedure would be to set a technological standard that forces firms to produce the high quality variant of the product. In spite that firms' feasible set is constrained, the "bad" equilibrium of the game is ruled out so firms end up being better off. Similar results could also be obtained with a Pigouvian tax that makes low environmental quality products more expensive for firms, as compared to high quality products.

It is convenient to highlight that, in our model, environmental quality has been a discrete choice for firms and this feature turns out to be crucial for the results. Firstly, this modelization allows us to have equilibria in which firms choose the same quality levels.[11] Secondly, the possibility to attain a win-win situation relies heavily on the fact that firms have limited degrees of freedom when choosing their quality levels. This is illustrated when we compare our results, for instance, with those in [3], where quality is a continuous variable. In their paper the introduction of a minimum quality standard never benefits both firms at the same time, as it does in our model.

Finally, it is worth mentioning that our results provide a theoretical foundation for the Porter hypothesis that rests on a pure market mechanism rather than on any market failure such as externalities or informational asymmetries. We also show, however, that despite the

[11] This is in contrast with the results in models of price-quality competition with continuous quality, in which the equilibrium always involves a certain degree of product differentiation. See, for instance, [6] and [17].

positive side-effect of environmental regulation in this context (i.e., making firms more profitable) the effect on consumer surplus is ambiguous. In this sense, our analysis suggests that using arguments based on the Porter hypothesis to support environmental regulation may fail to be appropriate unless a fully-fledged welfare analysis is undertaken.

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A Appendix

A.1 Proof of Proposition 1

First, note that the quality choice game is symmetric. This implies that there exists a Nash Equilibrium in pure strategies. Second, note that, in order to obtain a win-win situation, the initial and the final equilibrium of the game must be different. Otherwise, the payoff of the firm(s) playing s_H will remain unchanged and the firm(s) playing s_L will be worse off after the introduction of the penalty. Next, we show that the initial equilibrium must be (s_L, s_L). If the initial equilibrium is (s_H, s_H), the introduction of the environmental tax is irrelevant. If the initial equilibrium is either (s_L, s_H) or (s_H, s_L), then for the firm that chooses a low quality it holds that $\Pi^*_{LH} \geq \Pi^*_{HH}$. This ensures that the introduction of the environmental tax can never generate an increase in the profit of the firm which initially played s_L. Finally, we show that the final equilibrium must be (s_H, s_H). Since the final equilibrium must be different from the initial one, (s_L, s_L) is discarded. For (s_H, s_L) to be an equilibrium it is required $\Pi^*_{HL} - T > \Pi^*_{LL} - T$. But for (s_L, s_L) to be the initial equilibrium, we need $\Pi^*_{HL} < \Pi^*_{LL}$, which is a contradiction. By symmetry (s_L, s_H) is also discarded. ■

A.2 Proof of Corollary 1

$T > \Pi^*_{LH} - \Pi^*_{HH}$ is needed for (s_H, s_H) to be an equilibrium in the regulated quality choice game. $T > \Pi^*_{LL} - \Pi^*_{HL}$ is needed to prevent (s_L, s_L) from being an equilibrium in the regulated quality choice game. $\Pi^*_{HL} < \Pi^*_{LL}$ is needed for (s_L, s_L) to be an equilibrium in the unregulated game. Finally, $\Pi^*_{LL} < \Pi^*_{HH}$ is needed for the firms to be better off in the final Nash equilibrium than in the initial one. On the other hand, all these conditions together guarantee that a win-win situation occurs, so that they are both necessary and sufficient. ■

A.3 Proof of Proposition 2

We will show that for every $\alpha \in [0, 1]$ it holds that $\Pi^*_{HL} > \Pi^*_{HH}$ and, hence, that the resulting quality choice game is incompatible with the Porter hypothesis.

In order to prove it we use the fact that Π^*_{HL} is independent from α, while, for every $\alpha \in [0, 1]$ we can ensure that Π^*_{HH} is increasing in α. Then, it order to prove $\Pi^*_{HL} > \Pi^*_{HH}$ it suffices to prove $\Pi^*_{HL} > \Pi^*_{HH|\alpha=1}$.

We have that:

$$\Pi^*_{HL} > \Pi^*_{HH|\alpha=1} \iff$$

$$\left(\frac{2s_H\left(s_L\left(s_H - s_L\right) + cs_H\right)}{\Lambda}\right)^2 \left(s_H - s_L + c\right) > \frac{cs_H^2}{4\left(c+s_H\right)^2}.$$

After some straightforward algebraic manipulations it can be shown that the inequality above holds if and only if $\sum_{k=0}^{4}\left(\Psi_k\left(s_H, s_L\right)c^k\right) < 0$, where:

$$\begin{aligned}
\Psi_0\left(s_H, s_L\right) &= 16s_H^2 s_L^5 - 48s_H^3 s_L^4 + 48s_H^4 s_L^3 - 16s_H^5 s_L^2 \\
\Psi_1\left(s_H, s_L\right) &= s_L^6 + 22s_H s_L^5 - 32s_H^5 s_L - 79s_H^2 s_L^4 + 56s_H^3 s_L^3 + 32s_H^4 s_L^2 \\
\Psi_2\left(s_H, s_L\right) &= 12s_L^5 - 16s_H^5 - 56s_H s_L^4 - 48s_H^4 s_L + 20s_H^2 s_L^3 + 88s_H^3 s_L^2 \\
\Psi_3\left(s_H, s_L\right) &= 60s_H^2 s_L^2 - 12s_L^4 - 16s_H^3 s_L - 32s_H^4 \\
\Psi_4\left(s_H, s_L\right) &= 16s_H s_L^2 - 16s_H^3
\end{aligned}$$

Finally, we check that for every $k \in \{0,1,2,3,4\}$ and for every $s_H > s_L > 0$, it holds that $\Psi_k\left(s_H, s_L\right) < 0$.

This completes the proof. ■

A.4 Proof of Corollary 2

It is enough to check that $\overline{F}$ is increasing in α and $\underline{F}$ is decreasing in α.

We first show that $\overline{F}$ is increasing in α. Rewrite $\overline{F}$ as

$$\overline{F} = \frac{c}{4}\left(\beta\left(\alpha, s_H\right) - \beta\left(\alpha, s_L\right)\right), \text{with } \beta\left(\alpha, s\right) \equiv \frac{s^2\left(2-\alpha\right)\alpha}{\left(c+\left(2-\alpha\right)s\right)^2}.$$

It can be shown that $\frac{\partial\beta(\alpha,s)}{\partial\alpha}$ is monotonically increasing in s. This, together with the fact that $s_H > s_L$ ensures that $\overline{F}$ is increasing in α.

We now show that $\underline{F} \equiv \Pi^{*\prime}_{HL} - \Pi^{*\prime}_{LL}$ is decreasing in α. Since $\Pi^{*\prime}_{HL}$ is independent from α, it suffices to check the behaviour of $\Pi^{*\prime}_{LL}$. It follows that:

$$\frac{\partial\Pi^{*\prime}_{LL}}{\partial\alpha} > 0 \iff \alpha < \frac{2s_L + c_L}{s_L + c_L} = \hat{\alpha}.$$

Therefore, $\underline{F}$ is decreasing in α for all $\alpha \in \left(0, \min\left\{\frac{4}{3}, \hat{\alpha}\right\}\right]$. This completes the proof. ■

A.5 Proof of Proposition 3

>From the second inequality in (6), we have:

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

The second inequality in (6) is $\Pi^*_{HL} < \Pi^*_{LL}$. Note that Π^*_{LL} does not depend on s_H whereas Π^*_{HL} is increasing in s_H[12] and, moreover, $\lim_{s_H \to 0} \Pi^*_{HL} = 0$ and $\lim_{s_H \to \infty} \Pi^*_{HL} = \infty$. 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 $s_H < \tilde{s}_H$. ■

A.6 Proof of Corollary 3

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

If we evaluate $B(s_H, s_L, c_H, c_L)$ in $s_H = \frac{c_H}{c_L} s_L$ we have

$$\begin{aligned} &B\left(\frac{c_H}{c_L} s_L, s_L, c_H, c_L\right) > 0 \Longleftrightarrow \\ &\quad 16c_H^2 s_L \left(s_L \left(\frac{c_H}{c_L} - 1\right) + c_H\right)^3 (c_L + s_L)^2 - 4c_L^3 \left(\frac{c_H}{c_L} - 1\right) s_L \left(s_L \left(\frac{c_H}{c_L} - 1\right) + c_H\right) \\ &\qquad - 4c_H^2 c_L^2 (c_L + s_L) + 3 s_L c_H c_L^3 > 0. \end{aligned}$$

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 3, this implies that, whenever $\frac{s_H}{c_H} > \frac{s_L}{c_L}$, it holds that $B(s_H, s_L, c_H, c_L) > 0$, so $\Pi^*_{HL} > \Pi^*_{LL}$ and condition (ii) is not fulfilled. ■

A.7 Proof of proposition 4

Denote as $\theta_{s_i} \left(= \frac{p_{ii}}{s_i}\right)$ the consumer who is indifferent between buying and not buying when the prevailing quality is s_i $(i = H, L)$.

Proof of statement (1). Using (1) and the assumption $c_H = c_L \equiv c$, θ_{s_i} can be written as $\theta_{s_i} = \frac{c}{c + (2-\alpha) s_i}$. The difference between this threshold for s_H and s_L is

$$\theta_{s_H} - \theta_{s_L} = \frac{c}{c + (2-\alpha) s_H} - \frac{c}{c + (2-\alpha) s_L} = \frac{c(2-\alpha)(s_L - s_H)}{[c + (2-\alpha) s_H][c + (2-\alpha) s_L]} < 0$$

[12] 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.

so that $\theta_{s_H} < \theta_{s_L}$ and more demand is covered with s_H. Specifically, consumers with $\theta \in [\theta_{s_H} - \theta_{s_L})$ enter the market.

Proof of statement (2). From *statement (1)* we know that consumers with $\theta \in (\theta_{s_H} - \theta_{s_L}]$ are strictly better off with s_H because they enter the market so they get a positive (rather than zero) utility. In order to prove that those consumers with $\theta \in (\theta_{s_L}, 1]$ are also better off we use the following argument. We write the utility of a consumer with taste parameter θ buying quality s_i $(i = H, L)$ as $U_i = \theta s_i - \frac{cs_i}{c+(2-\alpha)s_i}$. After some algebra, we can write the utility difference between buying quality s_H and s_L as

$$U_H - U_L = \frac{(s_H - s_L)\left\{\theta\left[c^2 + c(2-\alpha)(s_H + s_L) + (2-\alpha)^2 s_H s_L\right] - 1\right\}}{(c + (2-\alpha)s_H)(c + (2-\alpha)s_L)}.$$

As $\theta_{s_L} > \theta_{s_H}$, for $\theta = \theta_{s_L}$ it necessarily holds that $U_H > U_L = 0$. This, together with the fact that $U_H - U_L$ is increasing in θ, ensures that $U_H > U_L$ also for $\theta \in (\theta_{s_L}, 1]$. This completes the proof. ■

A.8 Proof of Proposition 5

Proof of statement (1). From Corollary 3 we know that a win-win situation can only happen if $\frac{s_H}{c_H} < \frac{s_L}{c_L}$. Using the expressions for the equilibrium prices computed in subsection 3.2 this condition can be written as $\frac{p^*_{HH}}{s_H} > \frac{p^*_{LL}}{s_L}$. Taking into account that the demand of a good with environmental quality s_i is given by the mass of consumers with $\theta \geq \frac{p^*_{ii}}{s_i}$ (see Subsection 3.1), we can ensure that those consumers with willingness to pay for environmental quality $\theta \in \left[\frac{p^*_{LL}}{s_L}, \frac{p^*_{HH}}{s_H}\right)$ will exit the market after the introduction of the environmental policy.

Proof of statement (2). The individual with the highest willingness to pay for environmental quality ($\theta = 1$) is better-off after moving from (s_L, s_L) to (s_H, s_H) iff:

$$s_H - p_{HH} > s_L - p_{LL} \Longleftrightarrow \frac{s_H^2}{c_H + s_H} > \frac{s_L^2}{c_L + s_L}.$$

This can be rewritten as an upper bound on c_H. There is at least one individual who is better off, iff:

$$c_H < \frac{s_H^2}{s_L^2}(s_L + c_L) - s_H \equiv \bar{c}_H.$$

On the other hand, in order to obtain a win-win situation we need that (6) holds and, in particular, that:

$$\Pi^*_{HL} = \left(\frac{2s_H(s_L(s_H - s_L) + c_L s_H)}{\Lambda}\right)^2 (s_H - s_L + c_H) < \Pi^*_{LL} = \frac{c_L s_L^2}{4(c_L + s_L)^2}.$$

The envelope theorem ensures that Π_{HL} is decreasing in c_H. Since, in addition we have that Π_{LL}^* is independent of c_H, we can ensure that, if for $c_H = \bar{c}_H$, the condition $\Pi_{HL}^* < \Pi_{LL}^*$ does not hold, then it will not hold either for any $c_H < \bar{c}_H$.

In other words, if for $c_H = \bar{c}_H$, we have that $\Pi_{HL}^* > \Pi_{LL}^*$, then it is never possible to have simultaneously a win-win policy and that at least one consumer benefits from the change to (s_H, s_H).

If we evaluate Π_{HL}^* in $\bar{c}_H$, we have that checking $\Pi_{HL}^* > \Pi_{LL}^*$ is equivalent to checking $G(s_H, s_L, c_L) > 0$, where

$$G(s_H, s_L, c_L) \equiv \Pi_{HL}^*(\bar{c}_H) - \Pi_{LL}^* =$$
$$\frac{4s_H^2\left(s_H(s_L + c_L) - s_L^2\right)^2\left(\frac{s_H^2}{s_L^2}(s_L + c_L) - s_L\right)}{4s_H\left(\frac{s_H^2}{s_L^2}(s_L + c_L)^2 - s_L^2\right) - s_L\left(2s_Hc_L\left(1 + \frac{s_H}{s_L}\right) + 2s_H^2 - s_L^2 - s_Ls_H\right)} - \frac{c_Ls_L^2}{4(c_L + s_L)^2}.$$

Rewriting the equation above as an expression with the least common denominator of the form $\frac{A(s_H,s_L,c_L)}{B(s_H,s_L,c_L)}$, we can ensure that $B(s_H, s_L, c_L)$ is always postive. Therefore, the sign of $G(s_H, s_L, c_L)$ is determined by the sign of $A(s_H, s_L, c_L)$. Some tedious computations allow us to ensure that $A(s_H, s_L, c_L)$ is monotonically increasing in c_L. Therefore, a sufficient condition for $G(s_H, s_L, c_L)$ to take positive values is that $\lim_{c_L\to 0} A(s_H, s_L, c_L) > 0$. Evaluating the limit we have:

$$\lim_{c_L\to 0} A(s_H, s_L, c_L) = 16s_L^2 s_H^2 (s_H - s_L)^2 \left(s_H^2 - s_L^2\right).$$

This limit is always positive since $s_H > s_L$. Hence, we have shown that $G(s_H, s_L, c_L)$ is always positive and, hence, that a win-win situation always implies that every consumer that buys the good is worse off. ■

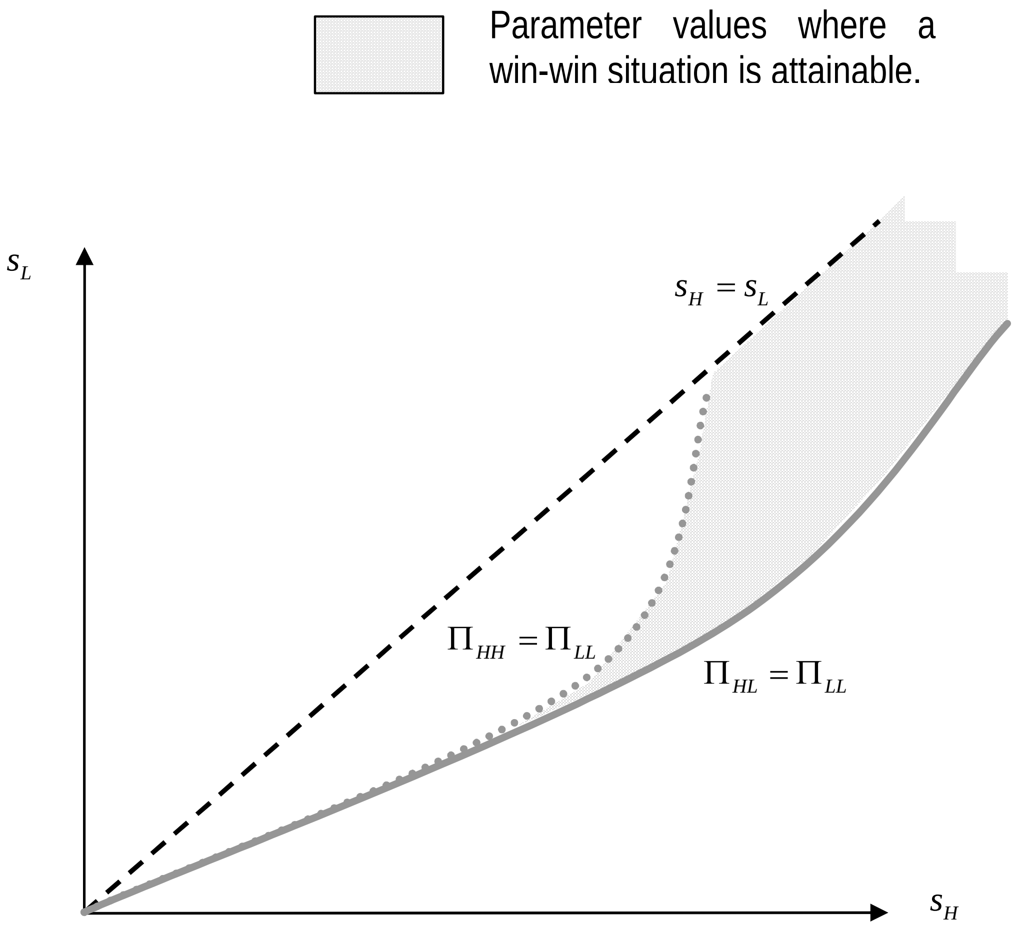

Figure 1: Example of win-win situations for $c_L = 100$ and $c_H = 500$ under marginal-cost pricing.