Environmental regulation as a coordination device for Introduction of a Green Product: The Porter’s hypothesis revisited

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Environmental Regulation as a Coordination Device for the Introduction of a Green Product: The Porter’s Hypothesis Revisited.

by

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Abstract:
According to Porter’s hypothesis, environmental regulation increases the regulated firms’ profits. However, if a “greener” strategy is more profitable why does it need regulatory intervention in order to be implemented?

Let a greener product increase the adopter’s marginal cost while providing no additional benefits during the first period. In the second period, when the product’s environmental attributes become known and appreciated by consumers, the adopter enjoys higher demand.

By adopting the green product alone, a firm loses profits in the first period due to a) its increased costs, and b) its reduced market share; in the second period, it enjoys additional profits due to c) its increased quality, and d) its increased market share. If both firms adopt the green product market shares remain unaffected, therefore b) and d) disappear. While simultaneously adopting the green product can be profitable for both firms, for a single firm to pioneer adoption may not be so. Environmental regulation acts, therefore, as a coordination device reducing market inertia. By inducing both firms to act simultaneously it allows them to pass from one Nash equilibrium to another one with higher profits.

JEL classification: Q20, Q28, L13, L50.
Key words: Porter’s hypothesis, environmental regulation, differentiated products, coordination.

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1. Introduction

The steady rise of environmental awareness during the recent few decades has resulted to an increase in all sorts of environmental regulations. However, environmental regulation measures increase, in both number and intensity, at a slower rate than environmental awareness, partly because of resistance from the regulated parties. Polluting industries oppose regulation, arguing that it will reduce profits and bring many activities to an end, and governments fear increases in unemployment and losses in the international competitiveness of domestic firms.

In this context, one can easily understand why the work of Porter and van der Linde (1995) stating that environmental regulation can increase profits and international competitiveness of the regulated firms, commanded so much attention. If this so-called “Porter’s hypothesis” is true, the dilemma between protecting the environment or protecting profits and/or international competitiveness of a domestic industry disappears and governments are encouraged to adopt strict measures for environmental protection.

As some other important results in economics,5 “Porter’s hypothesis” as initially stated is rather a conjecture, in that it has not been supported by a sound economic model. Moreover, it has been immediately criticized as parting from the principle of profit maximization. Indeed, if environmental protection yields profit opportunities then one wonders why profit maximizing firms need regulation to show them the way.6

In this paper we provide an explanation based on the fact that the adopter of the green product may lose market share until its product is recognized and fully appreciated by consumers. More specifically, we consider a case where consumers appreciate a greener version of a product with a time lag. The latter can be due to various reasons. First, consumers may require time in order to gather and process the information about the advantages of a new product. Second, they may not fully trust a firm’s claim about its product’s environmental properties. While labels may help in this direction, they often prove to be imperfect substitutes to time in forming opinions about a new product’s attributes. Third, when a country is at the beginning of the environmental-consciousness formation process, consumers may be slow in internalizing even a small part of the externality they create. For instance, a firm selling clean but expensive electricity may have little or no market share until consumers realize the importance of the environmental problem and this product’s contribution to it.

5 For instance the Coase conjecture.
6 The possibility of government possessing superior information about profit opportunities can easily be dismissed, at least in the majority of cases. For a review of the theoretical literature on the Porter hypothesis see Sinclair-Desgagné (1999), and Ambec and Barla (2000).
Similarly, a supermarket’s effort to reduce the use of plastic bags may involve costs that consumers may be unwilling to bear until they become fully conscious about their social usefulness.

Thus, the adoption of a green product (or process) often increases a firm's marginal cost without conferring any immediate benefits (first period). Later on (second period), when the product's environmental attributes become known and appreciated by consumers, the adopter enjoys higher demand.\(^7\)

If a firm acts alone in adopting the green product, market shares in both periods will be affected. This implies that in the first period the greener firm loses profits due to a) its increased costs and b) its reduced market share. Similarly, in the second period, the greener firm enjoys additional gains due to c) its increased quality and d) its increased market share. If both firms act together towards the adoption of the greener product, factors b) and d) disappear due to the symmetric nature of the situation. We show cases where, while it is profitable for both firms to switch to the greener product, it is preferable for a single firm to keep with the old product rather than pioneering the change on its own. In these circumstances, environmental regulation acts as a co-ordination device inducing both firms to act simultaneously, thereby allowing them to pass from a Nash-equilibrium to another, with higher profits.

The efforts to reconcile Porter’s hypothesis with profit maximization have followed two paths. The first emphasizes \emph{intra-firm} strategic interactions that may lead to constrained profit maximization due to principal-agent problems. Kennedy (1994) shows that a risk averse firm management may lead to underinvestment in R&D activities and that under specific circumstances environmental regulation can eliminate this internal inertia. For this to happen, the regulation-induced R&D investment must increase benefits disproportionately more in the good states, otherwise it would have been undertaken even without regulation. Sinclair-Desgagné (1999) and Ambec and Barla (2001) develop principal agent models to show that environmental regulation can help the firm reduce organisational inertia and thus, increase profits.

The second path focuses on \emph{inter-firm} interactions. Some studies have tried to relate the regulation-induced higher profitability to the fact that regulation may help relax

\(^7\) The always increasing consumers willingness to pay for both greener quality and greener production process, can be witnessed by the increasing importance of "Eco-labels" such as the ‘Blue Eco Angel’ (‘Blauer Engel’), a label attributed to products with high environmental features in the German market. This tendency goes beyond environmental considerations, as witnessed by the different ISO certifications.
competition. Ulph (1997) discusses environmental regulation in a strategic trade context, but shows that, while theoretically possible, it is rather difficult to find situations where regulation increases profits due to strategic trade effects. Other studies emphasize inter-firm externality correction. Mohr (2002) considers two production technologies, standard and green, and assumes that the production cost associated to each technology depends on the economy-wide accumulated capital used in this technology. Thus, even if the green technology results ceteris paribus in lower costs, it may not be used by an individual firm since the stock of capital employed with the old technology is much larger.

In our work, regulation succeeds increasing both firms’ profits not because it promotes cartelization or other forms of exercising market power, but because it provides the firm the green product adopter a safeguard against finding itself in a disadvantageous position. Regulation reduces, therefore, inertia due to first mover disadvantages, and in that respect our work is closest to that in Mohr (2002) where market inertia prevents the introduction of the green and more profitable technology. In Mohr’s work markets are competitive and inertia is due to a technological externality. In our work, inertia is created by consumer information problems and the presence of strategic effects in oligopoly markets.

The paper is structured as follows. Section 2 presents the model; section 3 solves for the subgame equilibria and arrives at the payoff matrix of the game’s reduced form; section 4 details the strategic effects that may validate Porter’s hypothesis; section 5 shows existence and performs comparative statics using specific functional forms for demand and cost; section 6 concludes. All proofs are relegated in the appendix.

2. The Model

We consider a Cournot-type duopoly where quantity competition is repeated twice. This structure can be represented by a three-stage game taking place in two periods. At the beginning of the first period both firms simultaneously choose their qualities (first stage). Having observed rival qualities they compete in quantities (second stage). In the second period (third stage) quantity competition is repeated.

The basic type of the good in question (type $P$) entails environmental damage—by either its production or consumption—which can be reduced or completely eliminated if the firms adopt the (eventually newly available) greener product type (type $V$). The latter can only be produced at a higher marginal cost.\(^8\) Formally, consider a regular cost function

\(^8\) Installing emissions control equipment (e.g., filters) often reduces the productivity of other inputs (the “indirect effect” in Barbera et McConnell (1990)). Fuel economizing cars require higher production costs and the
\[ C_i = C_i(q_i; s_i), \text{ where } s_i = P_i V, \text{ with } \frac{\partial C_i}{\partial q_i} > 0, \quad \frac{\partial^2 C_i}{\partial q_i^2} \geq 0, \quad C_i(0; s_i) = 0, \text{ and } \]
\[ \frac{\partial C_i(q_i; V)}{\partial q_i} = k \frac{\partial C_i(q_i; P)}{\partial q_i}, \text{ where } k \geq 1. \]

On the consumer side, we assume that once consumers perceive the difference between the two products, their willingness-to-pay for the green one is higher, \( i.e., \)
\[ P_r(q) \geq P_p(q), \quad \forall q. \] This preference may stem from various considerations. First, environmental quality is often correlated with other quality attributes. Organic products, for example, by avoiding fertilizers not only create less environmental damage, but are also considered as healthier. Second, and most important, a consumer may feel a moral obligation in contributing to environmental protection. In this sense, buying a greener product at a higher price corresponds to a voluntary contribution to a public good.\(^9\) The emergence of green energy markets constitutes an example of this case: according to Mirabel \textit{et al.} (2001), households in Switzerland accept a 10 to 20\% increase in their total electricity bill as a contribution towards a greener environment.

We assume that consumers do not immediately perceive the environmental quality of a product, realizing it, instead, with a time lag of one period.\(^{10}\) Three steps must be completed before a green product is considered of higher quality. First, environmental awareness must be developed. This is particularly important for green products that do not confer private benefits other than the “warm glow” from contributing towards a better environment.\(^{11}\) Second, the consumer must be convinced that the particular good or production process do indeed confer significant benefits. The magnitude of the long run health benefits from consuming organic produce must be evaluated before consumers decide if and how much they are willing to pay in order to substitute organic produce to standard one. Even nowadays many consumers ignore (or are not convinced of) these advantages, therefore, when facing the choice between the organic and non-organic version of a produce, they base their choice purely on price comparisons. Finally, even after consumers have been fully aware of the advantages from consuming the green product, they may not trust the product of any

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\(^9\) Voluntary contributions among a small number of agents may be positive in a Nash equilibrium even in the absence of “warm glow” effects. As the number of individuals increases, though, the role of such effects becomes crucial.

\(^{10}\) The extent of the time lag has no qualitative effects on our results.

\(^{11}\) This step can also be viewed as partial internalization of the environmental externality created by the consumption of a good. Its duration must be shorter for goods such as organic vegetables, since they also offer private health benefits. It also depends on the development of the overall environmental awareness. of a given country: for instance, it expected to be shorter in countries like Canada, Germany, or Belgium, compared to Greece or Albania.
particular firm as being indeed green. This is particularly important since green products often are of “credence goods” nature, *i.e.*, their quality may not be revealed even after consumption. For instance, it may take time for consumers to be convinced that a particular product is indeed organic, or a supplier’s electricity clean, as claimed by their respective producers. While eco-labels may help in this direction, the information lag may not disappear, since there may be a time needed for the product to be tested and the label to be attributed accordingly. Due to the aforementioned reasons, a reduction of the time interval necessary for trust to be built requires investments, the cost of which is usually convex in time reduction. It is, therefore, highly probable that the lag between a product’s introduction and its full acceptance will not be reduced to zero, and as a consequence, while a firm’s cost increases immediately upon the adoption of the green product, the benefits from increased demand appear only one period later.

To summarize, the two firms play a three-stage game over two periods. At the first stage (at the beginning of period 1) they choose simultaneously whether to continue with the conventional quality $P$ or to introduce the green product type $V$. At the second stage (period 1) they compete in quantities. At the beginning of period 2 consumers realize the real type of each product and the two firms compete once more in quantities. Firm $i$’s strategy is, therefore, a triplet $(s_i, q_{i1}, q_{i2})$ where the second subscript indicates time period, with $s_i \in \{V, P\}$, $q_{i1} : \{V, P\} \to R_+$, and $q_{i2} : \{V, P\}^2 \times R^2 \to R_+$. Since second period demand and costs do not depend on first period sales and no cooperation is allowed, we can simplify the second period best reply to $q_{i2} : \{V, P\}^2 \to R_+$. In other words, after the simultaneous choice of qualities we have a *repeated game* over the two periods. Note also that nothing changes if we allow firms to change their quality before the second period, since this will only increase their cost without providing any benefits to them.

3. Equilibrium

Four subgames (two of them symmetric) stem from the first stage, where firms choose their qualities. Each subgame is identified by the quality pair $S \equiv (s_1, s_2) \in \{V, P\}^2$ and consists of the two-period repeated Cournot-competition. As second period profits do not depend on first-

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12 Eco-labels aim precisely at reducing this informational lag. However, their effectiveness of labels may be limited by the fact that there may be *imperfect*, in that they do not succeed to fully convince consumers on a product’s quality, see Bonroy and Constantatos (2008). Also, the often observed discrepancy between laboratory-measured and actual performance may reduce the reliability of labels.
period actions within each subgame, each period’s equilibrium can be obtained separately in a very standard way. The inter-temporal profit of firm $i$ given a quality pair $S$ is:

$$\Pi_i(S) = \pi_{i1} (q_{i1}(S), q_{j1}(S), C(q_{i1}, s_i)) + \delta \cdot \pi_{i2} (q_{i2}(S), q_{j2}(S), C(q_{i2}, s_i))$$

(1)

$i,j=1,2$, $i \neq j$. Notice that if $\hat{S} \neq \hat{S}$, then $\pi_{i1} (\hat{S}) \neq \pi_{i1} (\hat{S})$ despite the fact that first period demand functions are similar across subgames, since, by moving from one subgame to another at least one firm’s marginal cost changes. Determining Cournot equilibrium for every possible subgame and substituting equilibrium quantities back into (1) results in the following payoff matrix of the reduced game:

$$\begin{array}{c|c|c}
\text{Firm 1} & \text{V} & \text{P} \\
\hline
\text{V} & \Pi_1(V,V), \Pi_2(V,V) & \Pi_1(V,P), \Pi_2(V,P) \\
\text{P} & \Pi_1(P,V), \Pi_2(P,V) & \Pi_1(P,P), \Pi_2(P,P) \\
\end{array}$$

Figure 1

The equilibrium of the overall game is, of course, parameter dependent. In the next section we construct an interpretation of Porter’s Hypothesis on the basis of this matrix.

4. Porter’s Hypothesis

Porter’s Hypothesis states that in many situations environmental regulation leads to higher profits for the regulated firms. Translated in our notation this implies that the $(V,V)$ entry in the above matrix is Pareto optimal for the two firms. In order to simplify notation, hereafter the first and second superscripts indicate the quality choice of firm $i$ and its rival, respectively, which allows us to define our first condition

- $\Pi_i^{VV} > \Pi_i^{PP}$, $i=1,2$ (Porter, or, $Po$ condition)

From (1) the profit difference between the situations of mutual adoption and mutual rejection of the green product, respectively, can be written as

$$\Pi_i^{VV} - \Pi_i^{PP} = \pi_{i1}^{VV} - \pi_{i1}^{PP} + \delta \left( \pi_{i2}^{VV} - \pi_{i2}^{PP} \right)$$

(2)

Notice that $\left[ \frac{\partial (\Pi_i^{VV} - \Pi_i^{PP})}{\partial \delta} \right] = \left( \pi_{i2}^{VV} - \pi_{i2}^{PP} \right)$, i.e., a small increase in $\delta$ increases the difference in the present value of profits by an amount equal to the difference in future profits.
Obviously, for the Porter condition to hold, it is necessary to have \( \pi_{i2}^{PV} - \pi_{i2}^{PP} > 0 \), which is assumed hereafter.

The usual critique to Porter’s hypothesis says roughly that if there are profits to be made, firms will not wait for the regulation to show them the way. In terms of our analysis this critique can be avoided under two conditions. The first is that \( (P, P) \) is a Nash equilibrium, therefore, no firm wishes to move alone towards the adoption of the green product. This market inertia is guaranteed by the following condition:

- \( \Pi_i^{PP} > \Pi_i^{PV} \quad i = 1, 2 \) (Inertia, or condition I)

Using (1) we can write:

\[
\Pi_i^{PP} - \Pi_i^{PV} = \pi_{i1}^{PP} - \pi_{i1}^{PV} - \delta \left( \pi_{i2}^{PV} - \pi_{i2}^{PP} \right)
\]

i.e., a small reduction in \( \delta \) increases inertia by an amount equal to the second period’s profit difference between adopting the green product and keeping the polluting version. When \( \left( \pi_{i2}^{PV} - \pi_{i2}^{PP} \right) < 0 \) condition I holds independently of \( \delta \), since the unilateral adoption of the green does not pay off even in the second period when consumers appreciate the green quality; such a case is ruled out.

Market inertia, however, may not be so strong as to require regulation if \( (V, V) \) is also an equilibrium. While in that case it still remains theoretically possible that firms be locked in the historical \( (P, P) \) equilibrium,\(^{13}\) it is hard to imagine that they will not find a coordinating device to lead them to the \( (V, V) \) equilibrium when the latter yields higher profits. We rule such cases of weak inertia out, by requiring that \( (V, V) \) be not a Nash equilibrium:

- \( \Pi_i^{PV} > \Pi_i^{VV} \quad i = 1, 2 \) (Dominance, or condition D)

Again, using (1) we can write:

\[
\Pi_i^{PV} - \Pi_i^{VV} = \pi_{i1}^{PV} - \pi_{i1}^{VV} - \delta \left( \pi_{i2}^{VV} - \pi_{i2}^{PV} \right)
\]

Conditions D and I establish \( (P, P) \) as the only Nash equilibrium of the entire game.\(^{14}\)

When all three conditions above are met, the situation resembles a classical prisoner’s dilemma: the two firms are locked in the \( (P, P) \) equilibrium, which is inferior from both social and private points of view. How can this happen? If a firm decides to move alone and adopt the green product during the first period its cost increases while its product is not

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\(^{13}\) Before society became conscious of the environmental problem, quality \( P \) had been both more profitable and socially desirable, due to its lower cost.
perceived as of superior quality. Besides the direct profit reduction (a), the higher marginal cost hurts the pioneer firm also through a reduction in its market share (b). As is the case in a typical asymmetric Cournot duopoly, a rise in the marginal cost of one firm shifts its best reply function inwards, thus resulting in less output for that firm and an output expansion for its rival. In the second period, the pioneer firm enjoys increased demand (c), and a product differentiation advantage (d), since that firm alone is the provider of the most preferred green quality. Condition I implies that the profit loss from (a) and (b) exceeds the benefits from (c) and (d), properly discounted. Condition D implies that if one firm pioneers the introduction of the green good, the other firm gains more by being laggard than by imitating the pioneer. When conditions I and D hold simultaneously, the introduction of the green good cannot be obtained without intervention, even if it guarantees higher profits for both firms in the event that condition Po holds as well.\(^1\) In other words, when all three conditions Po, I, and D, hold simultaneously the green product provides higher profits for firms, yet its adoption is impossible without some sort of regulatory intervention.

More formally, firm \(i\)'s profit function can be written as

\[
\Pi_i = \pi_{i1} \left( q_{i1} \left( C_i(s_i), C_j(s_j) \right), q_{i1} \left( C_j(s_j), C_i(s_i) \right), C_i(s_i) \right)
+ \delta \pi_{i2} \left( \left( q_{i2} \left( C_i(s_i), C_j(s_j), s_i, s_j \right), q_{j2} \left( C_j(s_j), C_i(s_i), s_i, s_j \right), C_i(s_i) \right) \right)
\]

(5)

If firm \(i\) changes the quality of its product by a small amount \(ds_i\), the resulting change in its profit will be

\[
\frac{d\Pi_i}{ds_i} = \left( \frac{\partial \pi_{i1}}{\partial C_i} + \delta \frac{\partial \pi_{i2}}{\partial C_i} \right) \frac{\partial C_i}{\partial \delta s_i} + \delta \frac{\partial \pi_{i2}}{\partial q_{j1}} \left( \frac{\partial q_{j1}}{\partial C_i} \right) \frac{\partial C_i}{\partial \delta s_i} + \delta \frac{\partial \pi_{i2}}{\partial q_{j2}} \left( \frac{\partial q_{j2}}{\partial C_i} \right) \frac{\partial C_i}{\partial \delta s_i} + \delta \frac{\partial \pi_{i2}}{\partial q_{j2}} \frac{\partial q_{j2}}{\partial \delta s_i}
\]

(6)

In the above condition \(s_j\) has been treated as exogenous. If, on the other hand, firm \(i\) knows that every change in its quality will be followed by an equal change in the quality of its rival, it is as if \(s_j = s_j(s_i)\) with \(\left( ds_j / ds_i \right) = 1\). The latter, together with cost symmetry, implies that \(\left( dC_j / ds_i \right) = \left( dC_j / ds_j \right) \left( ds_j / ds_i \right) = \left( dC_i / ds_i \right) \). Using this condition, the change in \(i\)'s profit due to a given change in its product's quality becomes:

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\(^1\) In fact, under these conditions \((P,P)\) is also a dominant strategy equilibrium.

\(^1\) Private introduction of the green good may only occur if the firms can sign a binding contract with penalties in case of deviation. Such contract is rather unlikely to be observed.
The decision on whether to adopt the green product depends on the sign of (6) when a firm moves alone, or (7) when both firms are to adopt the product simultaneously. In either case, the firm must take into account, besides the direct effects from changing its quality and cost, the strategic effects resulting from such a decision. Satisfaction of the Po condition implies that the sign of (7) is positive, while satisfaction of the I condition requires the RHS of (6) to have negative sign. Comparing (7) to (6) we note the presence of three terms in (7) that are absent in (6). The first two, \( \frac{\partial \pi_i}{\partial q_{i1}} \left( \frac{\partial q_{j1}}{\partial C_i} \right) \) and \( \frac{\partial \pi_i}{\partial q_{i2}} \left( \frac{\partial q_{j2}}{\partial C_i} \right) \), are positive, thus reducing the (negative) strategic effect due to increased cost. A firm that moves alone to adopt the green product will experience a reduction in its sales expressed by the middle section of (6) while the corresponding reduction from simultaneous adoption is given by the middle section of (7), which is less. This reflects the fact that moving alone reduces sales because of both higher marginal cost as well as cost disadvantage relative to the other firm. With simultaneous adoption, while both firms experience \textit{ceteris paribus} lower sales due to increased cost, marginal cost symmetry leaves market shares unaffected. The third term present in (7) but absent in (6), \( \delta \left( \frac{\partial \pi_i}{\partial q_{i2}} \right) \left( \frac{\partial q_{j2}}{\partial C_j} \right) \), is negative negative due to the product differentiation advantage from adopting the green product alone.

The above analysis shows that, by forcing the two firms to adopt the green product simultaneously, environmental regulation mitigates all the strategic effects, thus making the direct effects more pronounced. It is possible that, while the sum of direct effects plus “mitigated” strategic effects (RHS of (7)) is positive, when the “full” strategic effects are added to the direct ones (RHS of (6)) this sum becomes negative. In what follows, we investigate the conditions implying simultaneously positive RHS of (7) and negative RHS of (6), while taking also into account the satisfaction of the dominance condition.

5. Existence and Comparative Statics
In this section we show first the existence of cases where $P_0$, $I$, and $D$ hold simultaneously through the use of an example. Further, we examine the conditions that make such situations likely. Let the cost function of firm $i$ take the form $C_i = c(s_i) \cdot q_i^2$, with $c(P) = 1$ and $c(V) = k > 1$.

On the demand side assume a representative consumer whose utility function is:

$$U(q) = m + u(q),$$

where $m$ is the quantity of the numéraire consumed and $u(q)$ is a quadratic utility function depending on the vector $q$ of quantities consumed. The term $u(q)$ is assumed to take the form:

$$u(q_p, q_v) = \alpha_p q_p + \alpha_v q_v - \frac{1}{2} \left( \beta_p q_p^2 + \beta_v q_v^2 + 2 \gamma q_p q_v \right),$$

where $q_p$ and $q_v$ represent, respectively, the amount of the polluting and green product consumed by the representative consumer, with $\alpha_p, \beta_p, \gamma > 0$, $0 < \gamma < 1$. In order to simplify the model, we assume $\alpha_p = 1$ and $\alpha_v = a > 1$. The latter implies that type $V$ has a product differentiation advantage over type $P$, so one can speak about “qualities.” We further assume that $\beta_p = \beta_v = \gamma = 1$, which implies that there is no brand name differentiation between the two firms, i.e., products are homogeneous unless one firm produces the green and the other the polluting variety. The representative consumer spends their income $M$ among the available goods they perceive in order to maximize (8a). Assuming $M$ to be sufficiently large as to rule out corner solutions, this implies the maximization of

$$U(q) = u(q) + M - pq,$$

with respect to $q$, where $p$ is the vector of the corresponding market prices.

Since at the first period, no matter the quality choices of the two firms, all consumers perceive any product as being of type $P$, they maximize (8) subject to the constraint $q_v = 0$, where $q_v$ is total quantity available of the green product.\(^{17}\) The resulting inverse demand function is

$$p_{PP}^P (\cdot) = 1 - q_{PP}^P - q_{PP}^P,$$

where $q_{PP}^P + q_{PP}^P \leq 1$.

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\(^{16}\) The possibility that the sum of the strategic effects from a simultaneous move increases (instead of simply reducing by a lesser amount) an eventually positive direct effect, does not alter our discussion and conclusions.

\(^{17}\) While the utility obtained depends on the actual qualities purchased, the consumer’s choice is based upon perceived qualities, which may well differ from actual ones, due to the assumed information lag.
In the second period, the true product types are revealed, hence demand functions depend on the quality choices firms made at the first stage of the game. Thus, there are four possible pairs \( S \) (two of them symmetric), according to product availability in that period.

a) When both firms decide to produce the conventional \( P \) version, the demand function is again given by (9).

b) When both firms opt for the environmentally friendly version, in the second period the representative consumer maximizes (8) subject to \( q_p = 0 \), where \( q_p \) is total quantity of the polluting product available. This yields

\[
p_{v}^{vv}(\cdot) = a - q_{i}^{vv} - q_{j}^{vv}
\]

(10)

c) When firm \( i \) opts for the green while firm \( j \) for the basic quality, the inverse demand functions are:

\[
p_{v}^{vp}(\cdot) = 1 - q_{j}^{vp} - q_{i}^{vp}
\]

(11)

\[
p_{v}^{vp}(\cdot) = a - q_{i}^{vp} - q_{j}^{vp}
\]

(12)

Solving for the equilibrium quantities and substituting them back into the profit functions we obtain, for firm \( i = 1, 2 \):

\[
\Pi_{i}^{pp} = (1 + \delta) \frac{2}{25}
\]

(13)

\[
\Pi_{i}^{vv} = \frac{(1 + k)}{(3 + 2k)^{\frac{1}{2}}} \left(1 + \delta a^2 \right)
\]

(14)

\[
\Pi_{i}^{vp} = \frac{(1 + k)}{(8k + 7)^{\frac{1}{2}}} \left[9 + \delta(4a - 1)^2 \right]
\]

(15)

\[
\Pi_{i}^{vp} = \frac{2}{(7 + 8k)^{\frac{1}{2}}} \left\{ (2k + 1)^2 + \delta \left[2(1 + k) - a \right]^2 \right\}
\]

(16)

Equations (13)-(16) allow us to investigate whether the three conditions, \( P_o \), \( I \), and \( D \), hold simultaneously. Our analysis is carried in the \((k, \delta)\) space for a given value of \( a \) and shows the existence of a region such that all three conditions hold at the same time. A comparative statics exercise with respect to variable \( a \) verifies the robustness of our results.

Starting from the \( P_o \) condition, we obtain the following result

**Lemma 1:** Let \( \tilde{c}_p(a) = \frac{25a^2 - 23 + 5\sqrt{25a^4 + 18a^2 - 7}}{32} > 1 \). Then, \( \forall a > 1 \) and \( k \in \left[1, \tilde{c}_p\right] \).

\[
\exists \delta_p(k; a) = \frac{8k^2 - k - 7}{25a^2(1 + k) - 2(3 + 2k)} \in (0, 1), such that condition \( P_o \) is (is not) satisfied
∀ δ ≥ (>) δ. The function δ(·) has the following properties: δ(1) = 0, δ(κ) = 1,
(∂δ/∂κ) > 0 and (∂δ/∂α) < 0.

Proof: See the appendix.

The above lemma implies the existence of an upward sloping curve, such as δ, in figure 2, which separates the (k, δ) space into areas A_Po, A_Pn, according to whether the Po holds or not, respectively. Area A_Pn corresponds to the lightly shaded area on the figure.

According to intuition, increases in the relative production cost of the green product make, ceteris paribus, the Po condition less likely to hold. An appreciation of the importance of future profits brings about the opposite result. An increase in consumers’ appreciation of the green product shifts the δ curve to the right, thus enlarging the area where the Po condition holds.

Lemma 1 helped us translate the Po condition as an area in the (k, δ) space. The next lemma performs an analogous task for the I condition.

Lemma 2: Let κ = 100a(2a - 1) - 99 + \sqrt{8a^2 - 4a + 5}\left[100a(2a - 1) + 189\right] / 256 > 1. Then,

∀ a > 1 and k ∈ [1, κ], ∃ δI(k; a) = \frac{128k^2 - k - 127}{200a(1 + k)(2a - 1) - (128k^2 + 199k + 73)} ∈ (0, 1), such

that condition I is (is not) satisfied ∀ δ ≤ (>) δ. When k ≥ κ, condition I is satisfied for all
δ ∈ (0, 1] The function δI(·) has the following properties: δI(1) = 0, δI(κ) = 1,
(∂δI/∂k) > 0 and (∂δI/∂α) < 0.

Proof:

With the help of lemmita 1 and 2 we can show that

Proposition 1: When k ≤ κ(a) and δ < δ < min{δI, 1} then i) (P, P) is the only Nash equilibrium, and ii) (V, V) is Pareto superior to (P, P).

Proof: It is shown in the appendix (lemma 3) that for all couples (a, k), δI(k; a) ≥ δP(k; a), which implies that there is always a region where Po and I are simultaneously satisfied. For parameter values within that region, (P, P) is a Nash equilibrium despite the fact that (V, V) yields superior profits for both firms. Lemma 4 in the appendix shows that when inertia holds,
dominance also holds (the opposite is not true), which establishes makes \((P,P)\) as the unique equilibrium of the game, QED.

The situation is depicted in figure 1. In areas A, C, and D, the combination \((V,V)\) is Pareto optimal. In area D, \((V,V)\) is also the Nash equilibrium, therefore there is no need for regulation. In area C there are two asymmetric equilibria where only one firm introduces the green product without regulation. In areas A and B \((P,P)\) is the unique Nash equilibrium, hence, no firm introduces the green product in the absence of regulation. In area B we have the classical case where regulation enhances the environment but reduces firm profits. Finally, the most interesting case for our analysis is area A, where all three conditions \(Po, I\), and \(D\), hold simultaneously, therefore \((V,V)\) is Pareto optimal for the two firms but \((P,P)\) is the Nash equilibrium. Here regulation can both protect the environment and increase firm profits.

![Figure 1](image.png)

A tacit assumption in all our analysis is that the green product creates more social value when its superior environmental performance is taken into account. Proposition 1 says that the introduction of the green product cannot be profitable, unless a sufficient part of this additional value is translated into private (consumer) benefits. For \(k > \tilde{k}_p(a)\), even the undiscounted profit \((\delta = 1)\) is not sufficient for private profitability, hence, a necessary condition for profits to increase after the introduction of the green product is that \(k \leq \tilde{k}_p(a)\),
the maximum cost ratio that still allows the green product to be potentially privately profitable. Note that an increase in \( \hat{a} \) obviously pushes the entire \( \hat{\delta}(k; \hat{a}) \) curve to the right, thus increasing \( \hat{k}_p(a) \).

The above condition is necessary but not sufficient for our interpretation of Porter’s hypothesis for two reasons, both involving the discount factor \( \delta \). The first is that future profits heavily discounted have little present value. Heavy discounting may occur because consumers are slow to realize the green product’s quality and thereby internalize part of the externality. The positive slope of the \( \hat{\delta}_p \) curve expresses the fact that heavier discounting of future profits reduces the maximum value of \( k \) that allows the green product to generate higher profits.

However, when the undiscounted potential profitability is sufficiently high \( (k < k_f) \) too high values of \( \delta \) make private initiative possible and regulation unnecessary. For this reason, when \( k < \hat{k}_i \), only intermediate values of \( \delta \in [\hat{\delta}_p, \delta_i] \) allow for the simultaneous holding of both Inertia and Porter conditions. When \( k \in [\hat{k}_i, \hat{k}_p] \) then the necessary cost increase for the production of the green product is sufficiently high as to prevent unilateral production of the green product even when \( \delta = 1 \). In such cases any value of \( \delta \) that satisfies the Porter condition is consistent with our interpretation.

6. Conclusions

We have shown that in an oligopolistic market where consumers perceive a new product’s environmental quality with a lag, there may exist market inertia resisting the introduction of an otherwise profitable green product. This happens since unilateral adoption of the green product creates a strong negative strategic effect during the first period: the adopter finds itself in the position of the high cost player in an asymmetric Cournot game. Such thing would not happen had regulation forced both firms to switch to the green product simultaneously. In such a case while both firms’ first period profits would have been reduced, no firm would see its market share contracting. Based on this observation we have shown that in oligopolistic markets, Porter’s conjecture may be consistent with profit maximization.

The type of regulation we had in mind during our analysis is minimum quality standards. However, a tax on the polluting product could bring about the same result, namely induce firms to switch quality thereby increasing their profit. For that purpose the tax should be set at a level such that it would bring the marginal cost of the polluting product close to
that of the green one, as to eliminate the first period disadvantage of the green product adopter. Due to the simultaneous adoption of the green product, in equilibrium no firm would pay the tax, therefore both firms’ profits will be higher compared to the no tax situation. Since the high quality yields higher profits in the second period, the quality switching tax does not need to entirely eliminate the first period disadvantage, but simply to reduce it. What is interesting here is that the tax may not correspond to marginal environmental damage, but rather to the level that induces the quality switch.

Two assumptions are crucial in our analysis, a) that consumers respond with a lag to the introduction of the high quality, and b) Cournot competition. The first reflects either information lags about a product’s characteristics, or lags in the internalization of a part of the environmental externality. These lags must be more serious when the green product represents a drastic change relative to its polluting counterpart. While the presence of labels may help reduce such lags (i.e., reduce \( \delta \)), labels are often imperfect and not always trusted by all consumers.

While the case of Bertrand competition lies outside this paper’s scope, a few conjectures about that case may be in order. Unilateral adoption of the green product sends a signal for softer competition during the first period, thus increasing both firms’ profits. However, at least during the first period the adopter makes less profit than the non-adopter of the green product, and for some parameter configurations this can be true for the entire game. In such cases the situation looks like a battle of the sexes game, with two asymmetric equilibria and a symmetric one in mixed strategies. If the latter is played, there is a positive probability attached to no-firm adopting the green product in equilibrium. Regulation can again prevent market inertia and lead to higher profits for both firms.

Finally note that the type of market inertia developed in this paper is more general than the case of environmental goods on which it was applied, since it shows how the introduction of new product types can be impeded even in the absence of network externalities.

7. References
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8. Appendix

**Proof of Lemma 1:** For the Po condition to hold we must have

\[
\Pi_{j}^{PP} - \Pi_{i}^{PP} = \delta \left( \pi_{i1}^{PP} - \pi_{i2}^{PP} \right) - \left( \pi_{i1}^{PP} - \pi_{i2}^{PP} \right) = \frac{1+k}{(3+2k)^2} \left( 1 + \delta a^2 \right) - \frac{2(1+\delta)}{25} \geq 0 \quad (A.1)
\]

Solving the above for \( \delta \), we obtain

\[
\delta \geq \delta_p = \frac{\pi_{i1}^{PP} - \pi_{i2}^{PP}}{\pi_{i1}^{PP} - \pi_{i2}^{PP}} = \frac{8k^2 - k - 7}{25a^2(1+k) - 2(3+2k)^2} \quad (A.2)
\]

A necessary condition for Po to hold is that \( \pi_{i1}^{PP} - \pi_{i2}^{PP} > 0 \), i.e., the denominator of the above must positive, which implies \( k \in (1, \bar{k}_p) \), with \( \bar{k}_p = \left( \frac{25a^2 - 24 + 5a^2 \sqrt{25a^2 - 16}}{16} \right) \). On the other hand, \( \frac{\partial \delta_p}{\partial k} = \frac{50(a^2 - 1)(3 + 4k(k + 2))}{[25a^2(k + 1) - 2(2k + 3)^2]^{-2}} \geq 0 \), since \( a > 1 \), therefore, setting \( \delta_p = 1 \) and solving for \( k \) yields the maximum value of \( k \) for which there exists a discount factor that allows Po to hold; this corresponds to the value of \( \bar{k}_p \) as given in the lemma, and it can be easily shown that \( \bar{k}_p < \bar{k}_p \), for all \( a > 1 \). Further, \( \frac{\partial \delta_p}{\partial a} = -\frac{50a(k+1)(8k^2 - k - 7)}{[25a^2(k+1) - 2(2k + 3)^2]^{-2}} \leq 0 \), \( \forall a, k > 1 \). Finally, that \( \forall a > 1, \delta(1) = 0 \), is straightforward, QED.

**Proof of Lemma 2:** For the I condition to hold we must have

\[
\Pi_{i}^{PP} - \Pi_{i}^{PP} = \delta \left( \pi_{i1}^{PP} - \pi_{i2}^{PP} \right) - \left( \pi_{i1}^{PP} - \pi_{i2}^{PP} \right) = \frac{2(1+\delta)}{25} - \frac{9 + \delta(4a-1)^2}{(8k+7)^2} \geq 0 \quad (A.3)
\]

Solving the above for \( \delta \), we obtain

\[
\delta \leq \delta_I = \frac{\pi_{i1}^{PP} - \pi_{i2}^{PP}}{\pi_{i1}^{PP} - \pi_{i2}^{PP}} = \frac{128k^2 - k - 127}{200a(1+k)(2a-1) - (128k^2 + 199k + 73)} \quad (A.4)
\]

The expression of \( \tilde{k}_i \) in the lemma is obtained by setting \( \delta = 1 \) and solving for \( k \). The numerator of \( \delta_I \) being obviously positive, we require that the denominator be the same. The condition for the latter is

\[
1 < k \leq \tilde{k}_i = (1/256) \left[ 200a(2a - 1) - 199 + 5\sqrt{6400a^2(a-1) + 16a(214a - 57) + 89} \right].
\]

It can be shown straightforwardly that \( \forall a > 1, \tilde{k}_i < \bar{k}_i \), QED.

**Lemma 3:** \( \forall (a,k), \delta_I(k;a) \geq \delta_p(k;a) \).

**Proof:** After necessary simplifications, the \( \delta_I - \delta_p \) difference can be written as
\[
\delta_i - \delta_p = \frac{25(a-1)(k^2-1)(71+15a+64k)}{\text{Den}_i \cdot \text{Den}_p}
\]

(A.5)

Where \( \text{Den}_i, \text{Den}_p \) represent the denominator of (A.4) and (A.2), respectively, and are positive when \( \delta_i, \delta_p > 0 \). Since the numerator is also positive, it follows immediately that \( \delta_i > \delta_p \), QED.

**Lemma 4:** Holding of Inertia implies that \( \Pi_i^{PP} - \Pi_i^{PV} \geq 0 \) while holding of Dominance that \( \Pi_i^{PV} - \Pi_i^{VV} \geq 0 \). Let \( DI \) represent the difference between the LHS of the latter and the LHS of the former. Showing that \( DI \geq 0 \) implies that whenever Inertia holds then Dominance holds a fortiori. Using (13)-(16) we can write

\[
DI = \frac{M(k) + N(k,a)\delta}{[5(2k+3)(8k+7)]^2}
\]

(A.6)

where \( N = 25\left[113+k(199+88k)\right]a^2 - [20(3+2k)]^2(k+1)a \\
+ (2k+3)^2\left[127+3k(67+24k)\right], \text{ and } M(k) = \left[2(k-1)\right]^2\left[92+k(161+72k)\right] > 0, \forall k > 1. \)

The denominator of (A.6) being positive, the sign of \( DI \) depends on the sign of the numerator which is a linear function of \( \delta \). Since \( DI(\delta = 0) \approx M > 0 \) and \( DI \) is monotonic in \( \delta \), if \( DI(\delta = 1) \geq 0 \) then \( DI > 0, \forall \delta \). Setting \( \delta = 1 \), we get

\[
DI(\delta = 1) \approx M(k) + N(k,a) = \xi_1a^2 + \xi_2a + \xi_3
\]

(A.7)

where

\( \xi_1 = 2825 + 25k(199+88k) > 0, \quad \xi_2 = 4\{-900 + k\{-2123 + k[-1758 + k(-383+72k)]\}\}, \quad \xi_3 = 1511 + k[3333 + 4k(892+417k+72k^2)] \). The discriminant of the RHS of (A.7) turns out to be equal to \( -(k-1)^2\left(41143 + 144408k + 190968k^2 + 112768k^3 + 25088k^4\right) < 0, \forall k > 1 \). It follows that the RHS of (A.7) has the sign of \( \xi_1 \), hence \( DI > 0, \forall \delta \), therefore when inertia holds then dominance holds a fortiori, QED.