The Porter Hypothesis and Hyperbolic Discounting

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Abstract: We examine pollution-reducing R&D by a monopoly firm producing a dirty product. In a dynamic framework with hyperbolic discounting, we establish conditions under which the Porter hypothesis goes through, i.e. environmental regulation increases R&D, thus reducing pollution, as well as increasing firm profits. This is likely to hold whenever R&D costs are at an intermediate level, and the planning horizon of the firms is large.

Key words: Porter hypothesis, abatement tax, R&D, hyperbolic discounting.

JEL Classification No.: H2, L1, L2, L5.

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1 Introduction

The *Porter hypothesis*, originally developed by Porter (1991) and Porter and Linde (1995), is one of the most contested topics in environmental economics. The authors contend that environmental regulation creates a win-win situation by generating R&D that not only reduces pollution, but also increases firm profits. Arguably, the Porter hypothesis has led to a paradigm shift in environmental economics,[1] and is of great significance from a policy perspective (see, e.g. Gore, 1992).

Porter and Linde (1995) provide a series of case studies supporting their claim. From a theoretical point of view however, Portney (1994) and Palmer et al. (1995) challenge the validity of the Porter hypothesis. They use a simple static model of environmental regulation with a monopoly firm producing a dirty product, and deciding among two technologies that differ in their pollution levels to analyze the effects of stricter environmental regulations. They make the point that if a technology was not worth investing in before, then its benefits will not be enough to fully offset the costs of compliance after stricter regulations are enforced. Consequently it cannot be the case that an increase in environmental regulation makes R&D more attractive.

In this paper we seek to provide a theoretical foundation for the Porter hypothesis that, unlike most of the literature (discussed later), does not depend on strategic interactions. We consider a two period dynamic model with a monopoly firm producing a dirty product. This firm can either opt for an existing dirty technology, or invest in a cleaner technology. With hyperbolic (or present-biased) preferences we establish conditions such that an increase in environmental regulation can both reduce pollution, as well as increase firm profits - so that the Porter hypothesis goes through. This is likely to hold whenever the R&D costs are at an intermediate level, and the planning horizon of the firms is large.

[1]See, Kuhn (1970) for an interpretation of scientific revolutions as paradigm shifts.

We then briefly relate our paper to the literature. Following Portney (1994) and Palmer et al. (1995), the subsequent literature has tried to identify conditions under which environmental regulations can generate R&D, thus reducing pollution, as well as increasing firm profits. Simpson and Bradford (1996), for example, show that environmental taxes can lead to a reduction in R&D by foreign firms, thus increasing domestic profits. Xepapadeas and de Zeeuw (1999) demonstrate that environmental regulations can lead to an increase in average productivity via the modernization effect - i.e. a phasing out of inefficient capital. This can partially offset the increased costs of environmental regulation. Osang and Nandy (2003) focus on the external economies associated with R&D, showing that with large spill-over effects, emission caps may increase innovation incentives. Mohr (2002) also focuses on external economies, but in a general equilibrium framework. Roy Chowdhury (2009) identifies two new strategic effects, the relative efficiency effect and the competition softening effect, of environmental regulations under price competition. Kriechel and Ziesemer (2009) use a game of timing of technology adoption to examine the Porter hypothesis, showing that environmental tax will turn the preemption game with low profits into a game with credible precommitment generating higher profits.

Thus the literature has so far identified various strategic effects, namely first mover advantages, changing the composition of capital, the relative efficiency effect, external economies, etc. that can provide a formal foundation for the Porter hypothesis. The present paper adds to the literature by showing that in the presence of hyperbolic preferences, the Porter hypothesis may go through even in the absence of any strategic effects.

The rest of the paper is organized as follows. Section 2 discusses the basic framework, identifying conditions such that the Porter hypothesis goes through. Section 3 extends the analysis in several directions, while Section 4 concludes.

2 The Framework and Analysis

The model comprises a single monopoly firm producing a dirty product and facing a market demand of $f(q)$. We assume that $f(q)$ is continuous, negatively sloped and intersects both axes.

We next describe the technology. The existing technology is dirty, involving a production cost $c(q)$, with one unit of output generating one unit of pollution. By investing an amount F in R&D, the firm can however access a clean technology with cost function $\tilde{c}(q)$ that generates no pollution, and is efficient in that the cost function $\tilde{c}(q) < c(q), \forall q > 0$. Note that our formulation is in line with Xepapadeas and de Zeeuw (1999) who find that new vintages of capital are not only more efficient, but often less polluting than the earlier vintages. In the next section we extend the analysis to allow for more realistic R&D technologies, namely those that are non-deterministic, as well as lagged.

In order to bring out the logic of our argument in a transparent fashion, we begin by considering a lump sum abatement tax. Abatement tax thus takes the value $A > 0$ whenever pollution is positive, and is zero otherwise. We later allow for the case where the abatement tax varies continuously with the level of pollution.

Let

$$\pi(q) = qf(q) - c(q), \tag{1}$$

$$\tilde{\pi}(q) = qf(q) - \tilde{c}(q). \tag{2}$$

We make the following assumption on the demand and the cost functions.

Assumption 1. (i) The cost functions $c(q)$, $\tilde{c}(q)$ are both continuous (except possibly at the origin) and increasing in q, with $c(0) = \tilde{c}(0) = 0$.

(ii) $\pi(q)$ and $\tilde{\pi}(q)$ both have unique and interior maximizers.

Given Assumption 1, let

$$\pi^m = \max_q \pi(q), \tag{3}$$

$$\tilde{\pi}^m = \max_q \tilde{\pi}(q). \tag{4}$$

From a simple revealed preference argument, $\tilde{\pi}^m > \pi^m > 0$.

We consider a two period model, with $t = 1, 2$. Each period is further sub-divided into three stages. Consider period t, and suppose that the firm is yet to invest in R&D:

In *stage 1*, the firm decides on whether to incur the R&D costs F, or not. In case it does, the game goes to stage 2. Otherwise, the firm has the existing technology and the game goes to stage 3.

In *stage 2*, the R&D expenditure fructifies, and the firm has the clean new technology, with the production cost function $\tilde{c}(q)$.

Finally, in *stage 3*, the firm decides on its output level.

In case the firm has already invested in R&D in the earlier period, then the game goes directly to stage 3.

Note that even though the firm may invest in R&D in stage 1, even then it has to wait until stage 2 for the new technology to become available. While in our simple framework it would make no difference if stages 1 and 2 were coalesced, it is useful to keep this separation for conceptual clarity. Alternatively, one could coalesce stages 1 and 2, and interpret this model as one where the new technology is available off the shelf, and incurring F simply means buying (or licensing) this already available technology. One paper that clarifies this difference between investing in innovation and simply adopting a new, though existing, technology is Downing and White (1986).[2]

The firm's objective function is hyperbolic and is modeled using the stan-

[2] I am indebted to an anonymous referee for this point. In section 3 we re-visit the issue of R&D lag, using a simple framework where the R&D fructifies in stages, rather than instantaneously.

dard $\beta - \delta$ formulation.[3] For simplicity, we assume that $\beta = 0$, and $\delta = 1$. Letting U_i^t denote the firm's utility at stage i of period t

$$U_1^1 = \begin{cases} \pi^m - A, & \text{if the dirty technology is adopted,} \\ \tilde{\pi}^m - F, & \text{if the clean technology is adopted.} \end{cases}$$

$$U_2^1 = U_3^1 = \begin{cases} \pi^m - A, & \text{if the dirty technology is adopted,} \\ \tilde{\pi}^m, & \text{if the firm invests in R\&D.} \end{cases}$$

$$U_1^2 = \begin{cases} \pi^m - A, & \text{if the dirty technology is adopted,} \\ \tilde{\pi}^m - F, & \text{if the firm invests in R\&D in period 2,} \\ \tilde{\pi}^m, & \text{if the firm had invested in R\&D in period 1.} \end{cases}$$

$$U_2^2 = U_3^2 = \begin{cases} \pi^m - A, & \text{if the dirty technology is adopted,} \\ \tilde{\pi}^m, & \text{if the firm has invested in R\&D.} \end{cases}$$

We solve this model using a standard backwards induction logic. At this point it would be useful to define the notion of Porter hypothesis in this framework.

Definition. The Porter hypothesis holds for a pair of abatement taxes (A, A'), $A' > A$, if
(a) the firm opts for the polluting technology under A,
(b) but opts to invest in environmental R&D when abatement taxes increase to A', and
(c) the firm's present discounted profit (evaluated at $\delta = 1$) under A' exceeds that under A, i.e.

$$2\tilde{\pi}^m - F > 2\pi^m - 2A.$$

We next turn to the analysis. We demonstrate that whenever F is at an intermediate level (vis-a-vis the market parameters and A), there exists $A' > A$ such that the Porter hypothesis goes through.

[3]This was originally proposed by Phelps and Pollack (1968), and used by, among many others, Laibson (1997) and O'Donoghue and Rabin (1999).

Proposition 1 *Let* $2(\tilde{\pi}^m - \pi^m) > F - 2A > \tilde{\pi}^m - \pi^m - A$. *Then there exists* $\hat{A}$ $(> A)$ *such that for all* $A' > \hat{A}$, *the firm switches to the clean technology, and its discounted profit is higher compared to that under* A, *so that the Porter hypothesis goes through for* (A, A').

Proof. Suppose that the regulatory regime involves an abatement tax of A. Given the utility function of the firm, the firm adopts the clean technology at either period if and only if

$$\tilde{\pi}^m - F > \pi^m - A.$$

Given the second part of the hypothesis, this cannot hold. Next let

$$\hat{A} = \pi^m - \tilde{\pi}^m + F.$$

Thus for all $A' > \hat{A}$, the firm adopts the new technology.

Finally, given the first part of the hypothesis, the present discounted profit from adopting the clean technology under A', exceeds that from not adopting it under A, so that the Porter hypothesis holds. ■

The Portney (1994) and Palmer et al. (1995) critique relies on the following two-step argument. In case the firm does not adopt the clean technology under the existing level of abatement taxes, then, at this level of taxes, the present discounted profit under the dirty technology must exceed that under the clean technology. Hence, with stricter environmental regulations, the discounted profit under the dirty technology must continue to be higher than that under the clean technology. With a hyperbolic utility function, the first step of the argument need not be true, allowing the Porter hypothesis to hold.[4]

[4]Interestingly, most of the literature that appeals to strategic effects to justify the Porter hypothesis, relies on the fact that with strategic interactions the second step of the critique may be reversed.

It is easy to see that the Portney (1994) and Palmer et al. (1995) critique goes through in case the utility function of the monopolist is time consistent, i.e. $\beta = 1$. In that case under the existing abatement tax A, the polluting technology is adopted at $t = 1$ if and only if $2(\tilde{\pi}^m - \pi^m) < F - 2A$. But this implies that under A' also the present discounted payoff under the old technology exceeds that under the clean technology, thus violating the Porter hypothesis. Consequently, the hyperbolic nature of the utility function is critical to our results.

3 Discussion

In this section we extend the analysis in several directions.

$n \geq 2$ *periods.* Suppose there are $n \geq 2$ periods and let $\tilde{\pi}^m - F < \pi^m - A$. Consider $t = n$ and suppose that the clean technology has not been adopted so far. Clearly, given A, the firm does not adopt the clean technology, whereas for any $A' > \hat{A}$, where $\hat{A} = \pi^m - \tilde{\pi}^m + F$, the firm adopts the clean technology. Next a straightforward induction argument shows that if for any $t > 1$, it is the case that the dirty technology is chosen at A, and the clean technology is chosen for $A' > \hat{A}$, then the same must hold at $t = 1$.

We thus have

Proposition 2 *Let $\tilde{\pi}^m - F < \pi^m - A$. Then there exists $\hat{A} > A$ such that for all $A' > \hat{A}$, the firm selects the clean technology and, moreover, for a sufficiently large n, discounted firm profit under the clean technology exceeds discounted firm profits under the dirty technology (for A), i.e. $n(\tilde{\pi}^m - \pi^m) > F - A$.*

This shows that the Porter hypothesis is more likely to go through if the firm's planning horizon is long.

Generalizing the abatement tax function. Let the demand function be

$p = a - q$, $c(q) = cq$, $\tilde{c}(q) = \tilde{c}q$, where $\tilde{c} < c$, and two periods. Let the abatement tax be Ae, where e is the amount of pollution and A is the tax per unit of pollution, where $a > c + A$. Clearly, the abatement tax function adopted here is a linear version of that used by Barrett (1994). The pollution level under the dirty technology is $e(q) = q$, whereas $e(q) = 0, \forall q$ under the clean technology.

Observe that under the dirty technology the one period profit function of the firm is $\pi(q) = p(a - q) - (c + A)q$. Thus the optimal value of $\pi(q)$ is $\frac{(a-c-A)^2}{4}$, whereas under the clean technology the optimal one period profit of the firm is $\frac{(a-\tilde{c})^2}{4}$. Thus the dirty technology is chosen for any A such that

$$\frac{(a-c-A)^2}{4} > \frac{(a-\tilde{c})^2}{4} - F.$$

Further, the clean technology is chosen for any $A' > \hat{A}$, where $\hat{A}$ solves $\frac{(a-c-\hat{A})^2}{4} = \frac{(a-\tilde{c})^2}{4} - F$. Thus the Porter's hypothesis goes through for any abatement tax pair, (A, A'), whenever $A' > \hat{A}$ and A satisfies

$$2[(a-\tilde{c})^2 - (a-c-A)^2] > 4F > [(a-\tilde{c})^2 - (a-c-A)^2].$$

It is straightforward to construct parameter values such that these conditions are satisfied, thus establishing that our analysis is robust to a more realistic abatement tax function.

Non-deterministic R&D. Note that we assume that the new technology is deterministic, in that an investment of F yields the new technology with probability one. A more realistic assumption is that R&D is non-deterministic.[5] Suppose that in case the firm spends F on R&D in period 1, then it succeeds with probability λ, where $0 < \lambda < 1$. In case of success the firm has access to the new technology in both periods, whereas in case of failure it has access to the existing technology in both periods. For simplicity, we assume that once a firm invests in R&D in period 1 and fails, further

[5] I am indebted to an anonymous referee for this point.

investment in R&D at $t = 2$ will not lead to success, and there will be no further investment at $t = 2$. In case it did not invest in period 1 however, then it can invest F in period 2, when the success probability is again λ. It is now simple to derive the corresponding expressions for U_i^t. For this case note, for example, that $U_1^1 = \lambda\tilde{\pi}^m + (1-\lambda)(\pi^m - A) - F$ when the firm invests in innovation in the first period. Using these expressions and mimicing the argument in Proposition 1, we have

Proposition 3 *Let $2\lambda(\tilde{\pi}^m - \pi^m) - 2A'(1-\lambda) > F - 2A > \lambda(\tilde{\pi}^m - \pi^m) - A(2-\lambda)$. Then there exists (A, A'), where $A' > A$, such that for A' the firm switches to the clean technology and its discounted profit is higher compared to that under A, so that the Porter hypothesis goes through for (A, A').*

R&D lag. Finally we explicitly allows for the fact that R&D is not instantaneous.[6] Suppose that on investing F in R&D, it takes one period for the R&D to yield the full benefits, though there are some interim benefits. For simplicity, suppose that the interim technology has the same production cost function as the existing technology i.e. $c(q)$, though it is clean. Note that the net interim payoff from investing in the new technology is therefore $\pi^m - F$. In the next period (if there is one), the firm obtains the full benefit from the R&D, i.e. a cost function of $\tilde{c}(q)$, as well as a clean technology. Thus if the firm invests in R&D at $t = 1$, then its net payoff in $t = 1$ is $\pi^m - F$, and that in $t = 2$ is $\tilde{\pi}^m$. It is now routine to mimic the argument in Proposition 1 to show

Proposition 4 *Let $\tilde{\pi}^m - \pi^m > F - 2A > -A$. Then there exists $\tilde{A}$ ($> A$) such that for all $A' > \tilde{A}$, the firm switches to the clean technology and its discounted profit is higher compared to that under A, so that the Porter hypothesis goes through for (A, A').*

[6] I am indebted to an anonymous referee for encouraging me to work on this point.

4 Conclusion

The Porter hypothesis has important implications for policy, suggesting, as it does, that environmental regulation may lead to a win-win situation (so that the traditional cost-benefit analysis of environmental regulation may need to be qualified, at least in some cases). The validity of this argument has however been challenged by Portney (1994) and Palmer et al. (1995). Following this critique, the literature has focused on strategic interactions while trying to provide a foundation for the Porter hypothesis. The present paper extends the literature by showing that in the presence of hyperbolic preferences, the Porter hypothesis may go through even in the absence of any strategic interactions. This is likely to hold whenever R&D costs are at an intermediate level, and the firms have a large planning horizon.

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