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Can Environmental Regulations be Compatible with Higher International Competitiveness? Some New Theoretical Insights

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Abstract

Recently, the conventional view that stricter environmental regulations at home will affect the international competitiveness of the domestic firms negatively, has been challenged under the conditions that the regulated firms engage in innovation and that the environmental regulation is incentive-based. (This revisionist idea is known as the Porter hypothesis.) The considerable amount of empirical work in this literature as summarized in Jaffe and *et al* (1995) has not been able to generate evidence for either of these two views. Theoretical work is relatively limited and does not give much credit to the Porter hypothesis. We present some pro-revisionist theoretical evidence in a two-country model which incorporates Tradeable Emissions Permit as environmental regulatory regime. In such a model, firms subject to stricter environmental regulation can offset regulatory costs through innovation and/or permit revenues by abating more and selling extra permits. Finally, as a new idea, we suggest that consumers may have preference for the good that is produced in a relatively cleaner way, and thus, imposition of higher environmental standards at home can increase the demand for domestic production, and opens up a road towards increased competitiveness. Incorporation of this idea into our model brings further evidence for revisionist school.

1 Introduction

As environmental problems both on national and global level are getting more and more serious, public awareness on this issue is rising, and environmental regulations are being taken by an increasing number of countries. Environmental concerns have also attracted the attention of the academic circles, and a lot of new research areas are being openned. One of the earliest discussion topics was about the type of the regulation which comprises of command and control, effluent fees or taxes, tradeable emission permits, etc. Out of this discussion, incentive-based techniques (effluent fees, tradeable emission permits) were shown to be superior to non-incentive based techniques like command and control. Recently, there is a somewhat heated debate on the impact of incentive-based environmental regulations on the international competitiveness of the regulated firms, and we will explore this debate in this paper.

Conventionally, it was argued that environmental regulations would lower the competitiveness of the firms being regulated as compared to those subject to lax environmental conditions. This argument was assumed to be robust to the type of the environmental regulations. Recently, this view has been challenged by a revisionist school. They argue that properly crafted environmental regulations (i.e., incentive-based) not only bring social benefits with it (like increased environmental quality, decline in health risks associated with pollution, etc.), but also can increase competitiveness of the firms being regulated as higher environmental standards can trigger innovation that may offset the compliance costs. This debate is more explicitly seen in a series of papers published in Fall 1995 issue of Journal of Economic Perspectives, one by Palmer, Oates and Portney, and the other by Porter and van der Linde. We can associate *conventional school* with Palmer, Oates and Portney (1995) paper, and *revisionist school* with Porter and van der Linde (1995). The views of these two schools will be explored in the next two sections.

There are at least 100 empirical studies on this debate. This literature has been recently surveyed by Jaffe and *et al* (1995). They conclude, however, with the lack of evidence on either side:

> International differences in environmental regulatory stringency pose insufficient

> threats to U.S. industrial competitiveness to justify substantial cutbacks in domestic environmental regulations. Nor does the evidence recommend enactment of stricter domestic environmental regulations in order to stimulate economic competitiveness.

Theoretical work, relatively limited compared to empirical work, is in favour of conventional school; see for example, Pethig (1976), Siebert (1977), Yohe (1979) and McGuire (1982). Recently, Barrett (1994) shows that a "weak" environmental standard by domestic government may increase the competitiveness of a monopoly when the foreign industry is imperfectly competitive; if the domestic industry consists of more than one firm, this time there are incentives for "strong" standards[1]. However, these studies ignore innovation, which is an important part of Porter hypothesis. Simpson and Bradford (1996) included innovation in their modelling in which the environmental regulation is carried out by effluent taxes. They state that the impact of stricter environmental regulation on the performance of the industries being regulated would likely differ across sectors and be impossible to predict with any precision for any. They also conclude that it is difficult to construct examples in which tougher regulation should be enacted to enhance the long-run competitiveness of domestic industry, and thus, "tightening regulation to induce advantage may be extremely dubious as practical policy advice."

With this paper, we are willing to shed some new light, theoretically, on the relationship between environmental regulations and international competitiveness of the firms subject to higher environmental standards. In our model, the environmental agency uses *tradeable emission permits* regulation system, which was not studied before in this context. By doing so, we also make it possible to compare effluent tax system (studied by Simpson and Bradford 1996) with tradeable emission permits regarding to the international competitiveness of the regulated firms. We present evidences for the contentions of both school of thought. Although we take a neutral approach in this paper, our results show that Porter hypothesis should be given more credit as to its theoretical validity than the previous (theoretical) studies in this area conclude. We show that one does not need to deviate from the as-

[1] Strong (weak) standards mean that the marginal damage from pollution is less (higher) than marginal cost of abatement.

sumptions of the neoclassical model on the behavior of the firm (like X-inefficiency etc. as suggested earlier in this literature) to reach a theoretical support for the possible positive impact of environmental regulations on the international competitiveness of the firms being regulated.

We start with a closed economy, where two Cournot-oligopolists produce a good that causes pollution, to model the interactions among environmental regulations, competitiveness, and innovation. In this basic framework, we show that an increase in the stringency of incentive-based regulation, namely tradeable emission permits here, will not unambiguously lower the competitiveness of the firms. It is shown that among other things, the frontier between the two contentions on the impact of environmental regulation on competitiveness heavily depends on the features of the permit market like price elasticity of permit demand. With the introduction of stricter environmental policy (done by lowering the total amount of available permits), firms consider abatement seriously. There are two reasons for this: (i) they do not want to purchase costly permits that let them pollute, and (ii) they want to make use of the permits they already have to obtain permit revenues by selling them to those in need. These revenues will reduce the adverse effect of the regulation on the competitiveness of the firms. If the permit market is sufficiently inelastic, stricter policy may result in increased competitiveness for the regulated firms even if the firms do not innovate. Investment in R&D which results in innovation with some known probability, will make the increase in competitiveness more likely.

An important criticism of conventional school against revisionist school is why firms should not take all profitable opportunities before the regulation; i.e. if they can increase their profits by innovation or other means, why do they wait for environmental regulations? We provide an answer to this question by demonstrating that the regulatory policy causes changes in some parameters, like permit prices and price elasticity of demand for the good, which are outside the control of the firm but have impact on its decision. We show that some non-feasible R&D projects can become profitable after the enactment of stricter regulations because of the associated changes in these parameters.

Then, we move into open economy case where we assume the existence of a second country with again two Cournot-oligopolists, producing the same good. Our results in domestic case have their analogues here, and we present the conditions for when regulation worsens international competitiveness (conventional school) and when it improves international competitiveness (revisionist school). These conditions are determined by, among others, the probability of innovation, the cost of R&D, returns to innovation (new technology parameters), price elasticity of permit demand.

In addition to our analysis on production side, we also introduce a new idea that can affect regulation-competitiveness debate. We suggest that changes in environmental stringency influence not only supply side of the economy but also the demand side. As in the case of eco- or green-labelling, consumers may have preference for the good that is produced in a cleaner way; thus, the price elasticity of demand for the good that is produced under stricter regulation will be higher (in absolute value) than the one that is produced under relatively lax environmental conditions. Incorporation of this idea into our model brings support for revisionist school since higher environmental standards at home increases the demand for domestic production and opens up a new channel towards increased competitiveness.

Some very recent studies on the Porter hypothesis reinforce the theoretical results we present here. Xepapadeas and de Zeeuw (1998) show that downsizing and modernization of firms subject to environmental policy will increase average productivity, and will have positive effects on the marginal decrease of profits and environmental damage. They conclude, rather neutrally, that a win-win situation as suggested in the Porter hypothesis can generally not be expected, but the trade-off between environment and competitiveness is not so grim as is often suggested. A more strong case for the Porter hypothesis is provided by Albrecht (1998) in an empirical study. Albrecht (1998) considers a model for international CFC-regulation and the export performance of CFC-using industries like refrigerators, freezers, and air conditioning machines; he demonstrates that when regulation is linked to specific products, as in his case, there is clear evidence for the Porter hypothesis.

Sequentially, we present the views of the conventional and revisionist school. Our model and formal results follow these two sections. Concluding remarks are gathered in section 6.

2 Conventional School

In their 1994 paper, Oates, Palmer and Portney write:

> There has been widespread concern that the increasing stringency of domestic environmental regulation will put home-based industries at a competitive disadvantage in the international marketplace (see, for example, The Business Roundtable (1993)). According to this view, the increased cost that accompany more stringent controls will mean that domestic firms must confront their competitors abroad subject to an "unfair" burden. Such concern has even led to some proposed legislation in the form of a bill that would have introduced "counterveiling levies" against foreign nations whose "exports" benefit from the cost advantages associated with lax environmental programs.

By the very notion of profit maximization, the firm must have realized all the profitable opportunities and therefore environmental regulation, which is a constraint by itself, should not be expected to increase the profits of the firms being regulated[2]. If it were so, the firms would not have been realizing their profitable opportunities and thus they were operating inside their production possibilities. In brief, there are no $10 bills lying on the ground that need to be picked up. More specifically, it has been stated that environmental regulation imposes new significant costs on domestic firms, and thus, given the lax regulations abroad, they would experience a fall in their international competitiveness.

Theoretical studies in this literature present evidence for this view. One can see, Pethig (1976), Siebert (1977), Yohe (1979) and McGuire (1982). These studies did not take possible innovations that may come with stricter regulation into account. Recently, Simpson and Bradford (1996) included innovation in their model. Their results can be interpreted as a further support for the conventional school.

Palmer, Oates and Portney (1995) accepts the possibility that stricter regulation might result in innovation and innovation might offsett the costs associated with new regulation,

[2] They state that "The model essentially formalizes the basic point that the addition (or thightening) of constraints on a firm's set of choices can not be expected to result in an increased level of profits."

however, they say, this is very rare in practise. Moreover, even if regulation fosters innovation, it will harm competitiveness by crowding out funds for other potential (and possibly more productive) projects.

3 Revisionist School

This view is proposed by Porter (1991). Porter states that the trade-off between environmental stringency and international competitiveness comes from the "static" approach to the problem. In fact, if the analysis is carried through a "dynamic" framework[3], which mainly encompasses possibilities of innovation in technology, product, and processes, then there is room for improvement in international competitiveness as a result of stringent environmental regulation. It is true that environmental regulation increases the number of constraints that the firms are facing; however, it may motivate the firm towards innovation, which may offset the costs associated with stricter regulation. Porter and van der Linde (1995) state:

> ... we will argue that properly designed environmental standards can trigger innovation that may partially or more than fully offset the costs of complying with them. Such "innovation offsets" ... can not only lower the net cost of meeting environmental regulations, but can even lead to absolute advantages over firms in foreign countries not subject to similar regulations. ... In short, firms can actually benefit from properly crafted environmental regulations that are more stringent (or are imposed earlier) than those faced by their competitors in other countries. By stimulating innovation, strict environmental regulations can actually enhance competitiveness.

More explicitly, Porter hypothesis asserts that in general, the efficiency of an industry can be improved by more stringent environmental (or other) regulations either through sweeping inefficiencies out of the production process or through fostering innovation. As firms struggle to meet new environmental regulations, they reconsider their production

[3]The terms static and dynamic should not be considered in terms of a model that has an explicit time dimension, but rather in terms of the possibilities of innovation and other possible changes.

processes and they can discover new techniques in abatement (and possibly production) technology; thus, it may be the case that overall, the firms may experience a fall in their costs of production. Initially, these innovations have not been made because, facing lax environmental conditions, the firms did not have incentives to take the innovation process[4].

4 Model

Having introduced the views of both school of thought, now we can present our framework to analyze and demonstrate some new theoretical insights on the impact of environmental regulation on competitiveness. Firstly, we would like to take the case of a closed economy and see the interactions between environmental stringency, innovation and competitiveness of the firms. Then, given this basic set-up, we will extend it to the open economy setting where we can show our results related to regulation–international competitiveness debate.

Similar to the work of Sartzetakis and Constantatos (1995), we assume that two Cournot oligopolists produce a good that generates pollution. To concentrate on the effect of regulation on the competitiveness, we will try to make simplifying assumptions where necessary. So, marginal cost of production, c, is assumed to be same across firms and constant for analytical simplicity. Each firm maximizes its own profit taking the other firm's production decision into account. Inverse demand function is given by $p = a - bQ$, $a > 0, b > 0$, where p and Q represent price and demand of the good; supply of the good is $q_1 + q_2$, sum of the production of two firms, and so, $Q = q_1 + q_2$.

Since the production process generates pollution, the firms are required to take some abatement actions. The emissions are proportional to the firms' output levels, and so $E_i = rq_i$, where E_i is the emission demand of firm i and $r > 0$. Firms can reduce their emission levels either by decreasing the output level or by undertaking some abatement. Total abatement is represented by $A_i = \alpha_i q_i$, where α represents the abatement choice variable, with the corresponding convex abatement cost, $C_i = e_i A_i^2$, where e_i is a positive number.

[4] As we will show below, when environmental regulation is done through tradeable emission permits, changes in the permit prices with stricter regulation can make non-feasible projects profitable due to increases in permit revenues.

The environmental agency implements tradeable emission permits (TEP hereafter) regulation system to control aggregate emission level. As we stated above, the claim of revisionist school is that environmental regulation may increase competitiveness of the firm if environmental regulation is of the right type, right type being the incentive-based regulation as opposed to standard setting[5]. TEP is one example of incentive-based instruments, so it can be used to analyze Porter's hypothesis. In this system, firms must have a prespecified amount of permits to discharge a certain amount of pollution; for example, they may need to surrender one permit per unit of emissions. Firms can trade permits among themselves. A thorough analysis of tradeable permits can be found in Montgomery (1972).

Overall pollution is a result of many polluting industries inside the country. We assume that environmental regulation is applied to all polluting industries. We further assume that market for tradeable permits is perfectly competitive and thus firms take the permit prices, P^{ϵ}, that causes zero net demand for the permits as given. Each firm is given $\bar{E}$ amount of tradeable permits initially. Firm i's demand for permits is given by the difference between its desired level of emissions and abatement less of initial permit endowment, i.e. $E_i - A_i - \bar{E}$.

Thus, the optimization problem of each firm is as follows:

$$\max_{\mathbf{q_i},\alpha_\mathbf{i}} \quad \pi_i = pq_i - cq_i - e_i A_i^2 - P^{\epsilon}\left(E_i - A_i - \bar{E}\right) \tag{1}$$

Firms choose output and abatement level (through α) to maximize their profits. Replacing A_i and E_i in (1), we get an open form for firms' optimization problem:

$$\max_{\mathbf{q_i},\alpha_\mathbf{i}} \quad pq_i - cq_i - e_i(\alpha_i q_i)^2 - P^{\epsilon}\left(rq_i - \alpha_i q_i - \bar{E}\right) \tag{2}$$

where α_i is the choice variable related to optimal abatement level. As shown in appendix, the reaction function for firm i is given by:

$$q_i = \frac{a - c - rP^{\epsilon}}{2b} - \frac{1}{2}q_j \tag{3}$$

[5] For example, in case of Barrett (1994), government imposes environmental standards (command and control), and there is no room for innovation. These two do not conform to the requirements of the revisionist school. Therefore, that study should not be referred to for the comparison of the above school of thoughts.

Solving for optimal output levels, we get,

$$q_i = \frac{a - c - rP^\epsilon}{3b} \tag{4}$$

Firms produce the same level of output, which is not surprising under our symmetry assumptions[6]. Similarly the optimal abatement level is:

$$A_i = \alpha_i q_i = \frac{P^\epsilon}{2e_i} \tag{5}$$

The good will sell for,

$$p = a - b(q_1 + q_2) = \frac{a + 2c + 2rP^\epsilon}{3} \tag{6}$$

Upon the substitution of optimal values, corresponding profit levels will be:

$$\pi_i \quad = \quad \frac{(a - c - rP^\epsilon)^2}{9b} + \frac{(P^\epsilon)^2}{4e_i} + P^\epsilon \bar{E} \tag{7}$$

These values represent the positions of the firms before the stringent regulation program has been taken. It can be seen easily that the firm with lower abatement costs (i.e lower e) will have higher profits than the other firm. A change in P^ϵ, permit price, has ambiguous effects without further specification of the parameters of the model.

Before moving to the impact of a stringer environmental policy on the competitiveness of the firms, let us try to answer the following question first: can a regulated firm increase its profits over the non-regulated case when the environmental agency uses TEP system?

Proposition 1 *When the environmental regulation is done through TEP, it is possible for the regulated firm to have higher profits in the regulated case than in the non-regulated case if it earns enough revenues through permit market.*

Following a similar analysis above, if there is no regulation then the profits of the firm, which normally will not have any abatement activity, will be[7]:

$$\pi_i = \frac{(a - c)^2}{9b} \tag{8}$$

[6] If we had assumed a different average emission rate, r, across firms, then the firm with smaller emission rate would have produced more.

[7] Related maximization problem is $\max_{\mathbf{q_i}} \quad \pi_i = pq_i - cq_i$.

When we compare equation (8), profits of a non-regulated Cournot-oligopolist, with the one in (7), profits of regulated and abating Cournot-oligopolist, we can easily see that it is possible that regulated case can result in higher profits than non-regulated case due to positive effects arising from sales of emission permits. For a more concrete demonstration of this and necessary conditions, see appendix.

This proposition shows that it is conceivable that some of the firms will increase their profits after regulation; this may arise from the superiority of the abatement technology that they have at the time of regulation, or it may also be due to the initial permit allocation across the firms. Thus, the proposition has implications for the environmental agency, at least, in terms of the distribution of the permits initially.

Now, let us see the impact of a stringer environmental policy on the competitiveness of the firms.

4.1 Stricter Regulation, Innovation and Competitiveness

Environmental agency limits the number of permits that are available from $\bar{E}_T$ to $\tilde{E}_T$. As environmental regulation becomes more stringent, there are two options for the firms: status quo or innovation; that is to say, they may continue with their current production and abatement technology or they try to obtain a better abatement (and/or production) technology through increased investment in R&D. So, as a result of stringent regulation, with two firms, there are four possible behaviors:

Both firms choose to invest in R&D, or both continue without investing in R&D, or one of them decides to invest while the other does not.

Note that in this first part, we concentrate on domestic economy, and set up a framework through which the regulation and innovation process can be studied. Then, once we have this set-up, we can use it to obtain the relationship between *international* competitiveness and environmental regulation.

We assume that if the firm engages in R&D then it has to incur a cost of C_R and in return, with probability γ, it can get a new (abatement) technology, with parameters $\tilde{e}$, and

$\tilde{r}$ where $\tilde{e} < e$, and $\tilde{r} < r$. With probability $(1 - \gamma)$, firm will not be able to innovate, but it will still incur the cost of R&D[8].

We also note that a rise in stringency of environmental regulation will have impact on permit market because a fall in the total supply of permits will increase permit prices. A change in permit prices naturally generates incentives for the firm to change their decisions on the amount of production, level of abatement, and investment in R&D. As will be shown in more detail below, this kind of changes may make some projects that were not feasible before feasible and the profits of the firm might become higher than initial situation. We would like to note that changes in the permit market are *outside* the control of the firm; thus, this permit price externality associated with environmental regulation may change the value of the available projects to the firm. This is a reason why firms may not take the profitable projects before the stringent regulations, a main criticism of conventional school against revisionist school, and we provided an explanation why that criticism may not always be right. Let us begin to show the mechanics of this.

Case I:

In this case, none of the firms takes R&D, then the market share and profit level for each firm will be as follows (assume that $\tilde{P}^{\epsilon}$ represents new permit prices):

$$q_i = \frac{a - c - r\tilde{P}^{\epsilon}}{3b} \tag{9}$$

The corresponding profit levels will be:

$$\pi_i = \frac{\left(a - c - r\tilde{P}^{\epsilon}\right)^2}{9b} + \frac{\left(\tilde{P}^{\epsilon}\right)^2}{4e_i} + \tilde{P}^{\epsilon}\tilde{E} \tag{10}$$

If the permit demand is very price elastic, so that $\tilde{P}^{\epsilon}$ can be assumed to be very close to P^{ϵ}, then as seen from equations (4) and (9), market shares remain almost the same; however, the returns to each firm are expected be smaller with more stringent regulation since $(\tilde{E} < \bar{E})$. If permit demand is price inelastic, then permit prices do change considerably with stricter regulation. Since the supply of permits declined, permit prices will increase, $\tilde{P}^{\epsilon} >$

[8]We assume away the positive spillover effects of innovation across firms as it is not a major component of this debate.

P^ϵ, and thus each firm will produce less from equation (9); however, the impact on the profit levels is not clear. The increase in permit prices has both positive and negative effects on profit levels (the first term in (10) represents negative effect and the second and third ones represent positive one). Thus, it is conceivable that profits may increase with the tightening of environmental regulation even if the firms do not innovate.

Case II:

In this case, we assume that firm 2 engages in R&D, and firm 1 continues to use its old technology. Firm 2 is assumed to obtain a new technology with parameters $\tilde{r}$ and $\tilde{e_2}$ at a cost of C_R with probability γ. Also assume that permit demand is not very price-elastic and so P^ϵ rises to $\tilde{P}^\epsilon$. This will affect both the market shares, abatement and profit levels as follows: (note that firm 2 will now maximize its expected profits)

$$\begin{aligned}\max_{\mathbf{q_2},\boldsymbol{\alpha_2}} \quad & \gamma\left[pq_2 - cq_2 - \tilde{e}_2(\alpha_2 q_2)^2 - \tilde{P}^\epsilon\left(\tilde{r}q_2 - \alpha_2 q_2 - \tilde{E}\right) - C_R\right] + \\ & (1-\gamma)\left[pq_2 - cq_2 - e_2(\alpha_2 q_2)^2 - \tilde{P}^\epsilon\left(rq_2 - \alpha_2 q_2 - \tilde{E}\right) - C_R\right] \qquad (11)\end{aligned}$$

Firm 1's problem is as in case I; as shown in the appendix, the solution to the firms' problems will be:

$$q_1 = \frac{a - c - 2r\tilde{P}^\epsilon + (\gamma\tilde{r} + (1-\gamma)r)\tilde{P}^\epsilon}{3b} \qquad (12)$$

$$q_2 = \frac{a - c - 2(\gamma\tilde{r} + (1-\gamma)r)\tilde{P}^\epsilon + r\tilde{P}^\epsilon}{3b} \qquad (13)$$

$$A_1 = \frac{\tilde{P}^\epsilon}{2e_1} \qquad (14)$$

$$A_2 = \frac{\tilde{P}^\epsilon}{2(\gamma\tilde{e}_2 + (1-\gamma)e_2)} \qquad (15)$$

$$\pi_1 = \frac{\left(a - c - 2r\tilde{P}^\epsilon + (\gamma\tilde{r} + (1-\gamma)r)\tilde{P}^\epsilon\right)^2}{9b} + \frac{\left(\tilde{P}^\epsilon\right)^2}{4e_1} + \tilde{P}^\epsilon\tilde{E} \qquad (16)$$

$$\pi_2 = \frac{\left(a - c - 2(\gamma\tilde{r} + (1-\gamma)r)\tilde{P}^{\epsilon} + r\tilde{P}^{\epsilon}\right)^2}{9b} + \frac{\left(\tilde{P}^{\epsilon}\right)^2}{4(\gamma\tilde{e}_2 + (1-\gamma)e_2)} + \tilde{P}^{\epsilon}\tilde{E} - C_R \qquad (17)$$

Derivation of profit expressions in equations (16) and (17) are given in the proof of proposition 2 which we present now.

Proposition 2 *When the environmental regulation becomes more stringent, the firm that innovates will increase its market share and will undertake a higher abatement as compared to the one which does not innovate. That firm will also have a higher profit than the non-innovating firm, if, for example, the cost of innovation, C_R, satisfies*

$$(\tilde{P}^{\epsilon})^2 \; \frac{(e_1 - (\gamma\tilde{e}_2 + (1-\gamma)e_2))}{4e_1(\gamma\tilde{e}_2 + (1-\gamma)e_2)} > C_R \; .$$

Proof of the above proposition is presented in the appendix. To summarize, the first part, ($q_2 > q_1$), follows from equations (12) and (13) with the reminder that $(\gamma\tilde{r} + (1-\gamma)r) < r$, i.e. expected return to R&D is better than old technology. The second part requires us to show that the firm which tries to innovate will have higher returns as compared to status quo firm, i.e., $\pi_2 > \pi_1$.

The firm that engages in R&D benefits from the decrease in emission level at each output level (decline in r) and that generates a reduction in the cost of production and causes an increase in its market share as compared to the other firm. Note that the change in permit prices does not affect this result since both firms will be facing the same prices.

With a better "expected" abatement technology, the innovative firm produces a higher abatement (equations (14) and (15)); this is so because of a decline in the expected cost of abatement as represented by $(\gamma\tilde{e}_2 + (1-\gamma)e_2)$, which is assumed to be smaller than e_1. This brings about the possibility of a larger permit revenue for the innovating firm; through this channel, firm's expected profits tend to increase. Larger abatement imposes new costs on the firm but technological changes through R&D might offset these partially or fully. Also, the cost of R&D needs to be taken into consideration. Under certain conditions as shown in appendix in the proof of above proposition, environmental regulation increases the competitiveness of the firm which undertakes innovation; the status quo firm loses from stringent regulatory conditions. This is a variant of the Porter hypothesis. Environmental regulation is not in itself a reason for a loss in competitiveness. Moreover, we also recognize the possibility that stringent regulation may result in a loss in competitiveness of the innovative firm. This would be the case if the cost of the innovation is very high.

Related to this case, we can also prove one other interesting result. It is reasonable to assume that the innovation opportunities are there both before and after the regulation. So, the question is if innovation is increasing profits, why doesn't the firm invest to innovate before the stringent regulation? In fact, this is one of the main oppositions of the conventional school to the view of revisionist school. We take up this point now.

Proposition 3 *Due to changes in permit prices with the enactment of stricter environmental policies, it is possible that the projects that were not feasible before can become profitable for the firm.*

The proof is given in the appendix. The intuition behind this result is as follows. Stricter regulation increases permit prices, and thus, potential for higher permit revenues rises; however, it is uncertain whether the investment in R&D will bring about a better technology, and firm's subjective evaluation of possible innovation (as reflected in the magnitude of γ) can be such that firm does not find it to its interest to invest in R&D before the stricter regulation due to lower permit prices and higher innovation costs (this follows from the maximization of expected profits). As permit prices increase with new regulation, given the same prospect for the innovation, it may turn out that expected returns to R&D outweigh the cost of innovation, and thus firm decides to take the projects that it did not before. Thus, regulatory changes in the environment in which the firm operates can generate positive externalities through which previously non-feasible projects become feasible. Thus, in our model, we could answer the question why the firm does not innovate before but after stringent regulation by referring to the features of the permits market and innovation possibilities.

Case III

This case is associated with innovation by firm 1 and status quo by firm 2. The analysis will be exactly the same as case II when the positions of firms are interchanged.

Case IV

In this last case, both firms are motivated by stringent regulation and both of them invest in R&D. Assuming that the resulting technology parameters from innovation are same across firms with the same probability of innovation, the optimal values will be as follows:

$$q_1 = q_2 = \frac{a - c - (\gamma\tilde{r} + (1-\gamma)r)\tilde{P}^{\epsilon}}{3b} \tag{18}$$

$$A_i = \frac{\tilde{P}^{\epsilon}}{2(\gamma\tilde{e}_i + (1-\gamma)e_i)} \tag{19}$$

$$\pi_i = \frac{\left(a - c - (\gamma\tilde{r} + (1-\gamma)r)\tilde{P}^{\epsilon}\right)^2}{9b} + \frac{\left(\tilde{P}^{\epsilon}\right)^2}{4(\gamma\tilde{e}_i + (1-\gamma)e_i)} + \tilde{P}^{\epsilon}\tilde{E} - C_R \tag{20}$$

Then,

Proposition 4 *More stringent environmental regulation will result in increased profits for both firms if they undertake innovation and if the cost of innovation satisfies*

$$\frac{\left(\tilde{P}^{\epsilon}\right)^2}{4(\gamma\tilde{e}_i + (1-\gamma)e_i)} + \tilde{P}^{\epsilon}\tilde{E} - \frac{(P^{\epsilon})^2}{4e_i} - P^{\epsilon}\bar{E} > C_R.$$

Also note that the competitiveness of the firm is more likely to improve when it is the only one that innovates than when both firms innovate.

Proof of this proposition easily follows from the comparison of profit expressions in (20) and (7); note that first term of (20) is greater than that of (7), since $\gamma\tilde{r} + (1-\gamma)r < r$; under given condition, other terms in (20) also outweigh the ones in (7). Second part of the proposition can be shown by comparing (20) with the profit of the only innovating firm in case II, given by equation (17). Since $-2(\gamma\tilde{r} + (1-\gamma)r) + r > -(\gamma\tilde{r} + (1-\gamma)r)$, then $\pi_2 > \pi_i$; profit of the innovating firm will be higher when only one of the firms innovate than when both innovate.

Second part of the last proposition is interesting and may seem, at first reading, surprising. This is so because when both of the firms innovate, the market share of the innovating firm will be smaller as compared to the case when only one of them innovates as can easily be shown from the comparison of equations (13) and (18).

In this section, we showed the interactions between regulation, innovation and competitiveness in a domestic economy. Our results show that when the environmental regulation becomes more stringent, the profits of the regulated firms may move in either direction depending on returns to and cost of innovation, and also on the properties of the permit market. We note that upto this point, regulation is applied to all the firms in the market. The more interesting topic is what can be said about competitiveness if the regulation is applied exclusively as in the case of two country model in which one country imposes higher environmental standards at a trading equilibrium, and the other does not. This will be studied in the next section.

One other important result in this domestic case is our counter evidence to the earlier view that the Porter hypothesis could not be given credit theoretically if one does not move outside the rational behavior assumptions for the firm. (For example Palmer *et al* (1995) mentions about X-inefficiency, Simpson and Bradford (1996) states that Porter hypothesis call for specific cost functions.) In a simple model without any extreme assumptions on the behavior of the firms, we have not only shown that with the stricter regulation, the firm will be better-off (in terms of expected profits) if it invests in R&D than if it does not, but also it is possible that the firm can do better than the non-regulated case through innovation or even without innovation depending on the price elasticity of the permit demand. The key feature of our results is that the profits of the firm depend on permit revenues, and thus, the properties of the permit market is as important as innovation.

5 International Competitiveness and Regulation

Given this basic set-up for the interactions between regulation, innovation and competitiveness, now we can extend our results into open economy. Through this extension, we would be able to present evidences or counter evidences for the views of conventional and revisionist schools, and also see how the interactions between regulation, innovation and competitiveness compare in a closed economy versus in an open economy. We start with the description of a simple open economy.

We assume two countries, home (H) and foreign (F). Each country produces the same good. The demand for the product is represented by[9]

$$p = a - b(Q^H + Q^F) \quad .$$

As in the previous section, each country's output is produced by two Cournot oligopolists. Each country applies tradeable emission permit regulation policy, however the regulatory environment is relatively lax initially. We will investigate the effects of an increase in environmental controls in home country. Let us first determine the initial positions of the firms in each country. To make the analysis more tractable with four different firms, we assume that the firms are symmetric in every aspect inside and across the countries; this will help us to isolate the impact of environmental regulation on the competitiveness of the firms that are otherwise identical.

As shown in appendix, profit maximization results in following output, abatement and profit levels:

$$q_i^H = q_i^F = \frac{a - c - rP^\epsilon}{5b} \tag{21}$$

$$A_i^H = A_i^F = \frac{P^\epsilon}{2e} \tag{22}$$

$$\pi_i^H = \pi_i^F = \frac{(a - c - rP^\epsilon)^2}{25b} + \frac{(P^\epsilon)^2}{4e} + P^\epsilon \bar{E} \tag{23}$$

Initially, each country distributes $\bar{E}_T$ amount of permits among the firms. Since countries are assumed to be identical, output levels, abatement levels and profits are also identical.

[9]For ease of exposition, here we assume that home and foreign production are perfect substitutes for each other; however, our results are independent of this assumption. We will also present a case in which stricter regulation changes the demand for the good to the favour of those producing the good in a more environment-friendly manner; this has not been studied before.

At such an initial equilibrium position, home country puts new environmental regulations into effect and decreases the number of tradeable permits from $\bar{E}_T$ to $\tilde{E}_T$. The crucial question is what will happen to the competitiveness of the domestic firms (i) if they both continue with their present technologies, (ii) if both of the firms try to innovate and get a better technology at some cost, and (iii) if one of the firms tries to innovate and the other one keeps its old technology. Let us investigate each case seperately:

Case I:

In this case, we assume that none of the domestic firms takes R&D. The market shares of the firms will remain the same, if we assume that price elasticity of permit demand is very elastic; otherwise, permit prices, P^{ϵ} will increase in the home country and market shares of the domestic firms will fall and the share of foreign firms will rise; an expected result. Note that since environmental policy does not change in foreign country, permit prices will remain at P^{ϵ}. If the new permit price level at home is $\tilde{P}^{\epsilon}$, new output, abatement and profit levels will be as follows:

$$q_i^H = \frac{a - c + (2P^{\epsilon} - 3\tilde{P}^{\epsilon})r}{5b} \tag{24}$$

$$q_i^F = \frac{a - c + (2\tilde{P}^{\epsilon} - 3P^{\epsilon})r}{5b} \tag{25}$$

$$A_i^H = \frac{\tilde{P}^{\epsilon}}{2e} \tag{26}$$

$$A_i^F = \frac{P^{\epsilon}}{2e} \tag{27}$$

$$\pi_i^H = \frac{\left(a - c + (2P^{\epsilon} - 3\tilde{P}^{\epsilon})r\right)^2}{25b} + \frac{\left(\tilde{P}^{\epsilon}\right)^2}{4e} + \tilde{P}^{\epsilon}\tilde{E} \tag{28}$$

$$\pi_i^F = \frac{\left(a - c + (2\tilde{P}^{\epsilon} - 3P^{\epsilon})r\right)^2}{25b} + \frac{(P^{\epsilon})^2}{4e} + P^{\epsilon}\bar{E} \tag{29}$$

Market share of the foreign firms will exceed those of domestic firms; this follows from equations (24) and (25); since $\tilde{P}^\epsilon > P^\epsilon$, then $(2P^\epsilon - 3\tilde{P}^\epsilon) < (2\tilde{P}^\epsilon - 3P^\epsilon)$, and so $q_i^H < q_i^F$. Comparison of profit levels (and so competitiveness) is not as straightforward. If permit demand is very price elastic so that $\tilde{P}^\epsilon \approx P^\epsilon$ and since $\bar{E} > \tilde{E}$, then we will have $\pi_i^F > \pi_i^H$, which is a support for the view of conventional school. In general, $\tilde{P}^\epsilon > P^\epsilon$, and comparison of profits becomes more difficult. Depending on price elasticity of permit demand, and the amount of available permits, there will be evidences for conventional school or revisionist school. Note that, in this case, regulated firms are assumed not to take any R&D investment; the possibility of innovation will be considered in the next two cases. The inter-firm comparison can also be coupled with the comparison of the profits of the firm across regulation stringencies. This is very clear in foreign firms case; since $P^\epsilon < \tilde{P}^\epsilon$, then $(2\tilde{P}^\epsilon - 3P^\epsilon) > -P^\epsilon$, and so the profits of the foreign firms after stringer regulation (equation (29)) is greater than their profits before regulation (equation (23)). We can state this more formally,

Proposition 5 *Stricter regulation at home country will make foreign firms better-off unconditionally; however, there may be cases in which their improvement will be less than that of the domestic firms depending on the properties of permit market.*

The last part of the proposition above follows from the comparison of equations (28) and (29); it is conceivable that $\pi_i^H \geq \pi_i^F$. The first part is already shown in the last paragraph above.

Now, let us continue with the more important case where regulated domestic firms take actions for innovation with the imposition of stricter standards.

Case II:

In this case, domestic firms engage in R&D, and they succeed in innovation with a probability of γ. As above, new technology variables will be $\tilde{e}$ and $\tilde{r}$. Also, permit prices in home country rise to $\tilde{P}^\epsilon$ with stricter regulation. The resulting values of output, abatement and profit levels for both domestic and foreign firms are as follows:

$$q_i^H = \frac{a - c + 2rP^\epsilon - 3R_E\tilde{P}^\epsilon}{5b} \tag{30}$$

$$q_i^F = \frac{a - c + 2R_E\tilde{P}^\epsilon - 3rP^\epsilon}{5b} \tag{31}$$

$$A_i^H = \frac{\tilde{P}^\epsilon}{2(\gamma\tilde{e} + (1-\gamma)e)} \tag{32}$$

$$A_i^F = \frac{P^\epsilon}{2e} \tag{33}$$

$$\pi_i^H = \frac{\left(a - c + 2rP^\epsilon - 3R_E\tilde{P}^\epsilon\right)^2}{25b} + \frac{\left(\tilde{P}^\epsilon\right)^2}{4(\gamma\tilde{e} + (1-\gamma)e)} + \tilde{P}^\epsilon\tilde{E} - C_R \tag{34}$$

$$\pi_i^F = \frac{\left(a - c + 2R_E\tilde{P}^\epsilon - 3rP^\epsilon\right)^2}{25b} + \frac{(P^\epsilon)^2}{4e} + P^\epsilon\bar{E} \tag{35}$$

where $R_E = \gamma\tilde{r} + (1-\gamma)r$. Then,

Proposition 6 *When environmental regulation becomes more stringent at home, and the domestic firms innovate after environmental regulatory change, market share of the domestic firms will increase if* $rP^\epsilon > R_E\tilde{P}^\epsilon$*; the firms in home country will undertake a higher level of abatement as compared to foreign country. Finally, domestic firms will be more competitive if the following condition also holds*

$$\frac{\left(\tilde{P}^\epsilon\right)^2}{4(\gamma\tilde{e} + (1-\gamma)e)} + \tilde{P}^\epsilon\tilde{E} - \frac{(P^\epsilon)^2}{4e} - P^\epsilon\bar{E} > C_R\ .$$

The proof is presented in the appendix.

Depending on the values of new technology parameters ($\tilde{e}$ and $\tilde{r}$), the cost of R&D, C_R, price elasticity of permit demand, and the probability of innovation, γ, our model presents evidence for the view of revisionist school or that of conventional school. Under the conditions of the proposition, we have pro-revisionist results: the domestic firms not only increase their profits over the profits of the foreign firms but also over their pre-regulation profits (shown in appendix). Moreover, the post-regulation profits of foreign firms after the introduction of stricter regulation at home country will be less than their pre-regulation profits[10], which follows from the comparison of profit expressions in (23) and (35). One should emphasize the role of price elasticity of permit demand on these conclusions. If we assume $rP^{\epsilon} < R_E\tilde{P}^{\epsilon}$, i.e the opposite case, then we will get pro-conventional results. Relative magnitudes of r and $R_E = \gamma\tilde{r} + (1-\gamma)r$, show the partial impact of innovation on this debate.

How does this case compare to the one in which only one of the domestic firms innovate? Will the competitiveness of the innovating firm be higher than this case? We take up these questions now.

Case III

This case is associated with R&D by firm 1 and status quo by firm 2 in home country. The resulting output, abatement, and profit levels are as follows:

$$q_1^H = \frac{a - c + 3rP^{\epsilon} - 4R_E\tilde{P}^{\epsilon}}{5b} \tag{36}$$

$$q_2^H = \frac{a - c + R_E\tilde{P}^{\epsilon} - 2rP^{\epsilon}}{5b} \tag{37}$$

$$q_1^F = q_2^F = \frac{a - c + R_E\tilde{P}^{\epsilon} - 2rP^{\epsilon}}{5b} \tag{38}$$

$$A_1^H = \frac{\tilde{P}^{\epsilon}}{2(\gamma\tilde{e} + (1-\gamma)e)} \tag{39}$$

$$A_2^H = \frac{\tilde{P}^{\epsilon}}{2e} \tag{40}$$

$$A_i^F = \frac{P^{\epsilon}}{2e} \tag{41}$$

$$\pi_1^H = \frac{\left(a - c + 3rP^{\epsilon} - 4R_E\tilde{P}^{\epsilon}\right)^2}{25b} + \frac{\left(\tilde{P}^{\epsilon}\right)^2}{4(\gamma\tilde{e} + (1-\gamma)e)} + \tilde{P}^{\epsilon}\tilde{E} - C_R \tag{42}$$

[10] This is a result of the assumption that $rP^{\epsilon} > R_E\tilde{P}^{\epsilon}$. If we reverse this assumption, the profits of the foreign firms will increase with stricter regulation ad in proposition 5.

$$\pi_2^H = \frac{\left(a - c + R_E \tilde{P}^\epsilon - 2rP^\epsilon\right)^2}{25b} + \frac{\left(\tilde{P}^\epsilon\right)^2}{4e} + \tilde{P}^\epsilon \tilde{E} \tag{43}$$

$$\pi_1^F = \pi_2^F = \frac{\left(a - c + R_E \tilde{P}^\epsilon - 2rP^\epsilon\right)^2}{25b} + \frac{(P^\epsilon)^2}{4e} + P^\epsilon \bar{E} \tag{44}$$

where R_E is defined above.

Proposition 7 *When environmental regulation becomes more stringent at home, and one of the domestic firms innovate while the other does not, market share of the innovating firm will become larger than those of the non-innovating domestic firm and the two foreign firms if $rP^\epsilon > R_E \tilde{P}^\epsilon$. The innovating domestic firm will abate more than the other firms. Its competitiveness will rise relative to all other firms if the cost of R&D satisfies*

$$\frac{\left(\tilde{P}^\epsilon\right)^2}{4(\gamma\tilde{e} + (1-\gamma)e)} + \tilde{P}^\epsilon \tilde{E} - C_R \geq \frac{(P^\epsilon)^2}{4e} + P^\epsilon \bar{E}.$$

Finally, the returns to innovation will be higher when only one firm innovates than when both firms innovate.

This result is very much in accordance with the Porter hypothesis. Revisionist school claims that stricter environmental regulation should motivate firms to invest in R&D to innovate, and innovation will generate positive impact on the competitiveness of the firms by lowering the costs of the production. They suggest that innovation motivated by environmental concerns can also bring about a fall in the non-abatement cost of production which will improve the competitiveness further. In this paper, we showed that even if innovation does not bring about a fall in the non-abatement costs of the firm, the changes in abatement technology through innovation and the changes in the permit market arising from environmental regulation may be enough to offsett the burden associated with the new environmental regulation. Since our results are conditional, we again need to stress that they may be used as evidences for both school of thoughts; nevertheless, our results include stronger pro-revisionist theoretical evidence than the previous studies in this literature.

5.1 Demand-Side Effects

Now, we present one new idea on the regulation–competitiveness debate. We suggest that changes in environmental policies may affect not only the supply side of the economy but also the demand side. In fact, a similar statement on this topic has been made earlier by Smith and Espinosa (1996). They write that "pollution itself may alter the composition of goods demanded". Similarly, environmental regulation can also change the demand for private goods: consumers may have preference for the good that is produced in a cleaner way. This idea is strengthened by the existence of the practices known as eco- or green-labelling. These labels give information about the product on environmental grounds to attract consumers to buy. In our case, when the environmental regulation at home country becomes more stringent, the demand for the domestically produced good may increase. We can formulate this by the following demand function:

$$p = a - b_h Q^H - b_f Q^F$$

with $b_h < b_f$, which implies that price elasticity of demand is higher (in absolute value) for Q^H than Q^F. Under this modification, the optimal output, and abatement level and the profits of the domestic and foreign firms will be as follows:

$$q_i^H = \frac{a - c - rP^\epsilon}{5b_h} \tag{45}$$

$$q_i^F = \frac{a - c - rP^\epsilon}{5b_f} \tag{46}$$

$$A_i^H = A_i^F = \frac{P^\epsilon}{2e} \tag{47}$$

$$\pi_i^H = \frac{(a - c - rP^\epsilon)^2}{25b_h} + \frac{(P^\epsilon)^2}{4e} + P^\epsilon \bar{E} \tag{48}$$

$$\pi_i^F = \frac{(a - c - rP^\epsilon)^2}{25b_f} + \frac{(P^\epsilon)^2}{4e} + P^\epsilon \bar{E} \tag{49}$$

These derivations are similar to the ones in international competitiveness section above, and can be easily seen refering to related section in appendix by incorporating the new parameters b_h and b_f.

Note that total production of domestic firms are larger than that of foreign firms; moreover, the profits of the domestic firms are higher than the profits of the foreign firms since $b_h < b_f$. Using these as a starting point, we finish our analysis with the following proposition:

Proposition 8 *If consumers have higher preference for the good that is produced under stricter environmental regulation (i.e. in a more environment-friendly manner), then an increase in international competitiveness of the regulated firms becomes more likely.*

Equations (45)-(49) represent the situation where the price elasticity of demand differs across home and foreign countries; there may be many different reasons for such a difference. Let us assume that the reason for the difference in price elasticity of demand across countries is the imposition of new stringer environmental regulation at home country through a limitation in the number of permits; thus the permit prices in home country will be $\tilde{P}^{\epsilon}$ and amount of permits that a domestic firm has is $\tilde{E}$. Modifying equations (45)-(49), and assuming that there is no investment in R&D after new regulation, we get

$$q_i^H = \frac{a - c + r(2P^{\epsilon} - 3\tilde{P}^{\epsilon})}{5b_h} \tag{50}$$

$$q_i^F = \frac{a - c + r(2\tilde{P}^{\epsilon} - 3P^{\epsilon})}{5b_f} \tag{51}$$

$$\pi_i^H = \frac{\left(a - c + r(2P^{\epsilon} - 3\tilde{P}^{\epsilon})\right)^2}{25b_h} + \frac{\left(\tilde{P}^{\epsilon}\right)^2}{4e} + \tilde{P}^{\epsilon}\tilde{E} \tag{52}$$

$$\pi_i^F = \frac{\left(a - c + r(2\tilde{P}^{\epsilon} - 3P^{\epsilon})\right)^2}{25b_f} + \frac{(P^{\epsilon})^2}{4e} + P^{\epsilon}\bar{E} \tag{53}$$

To see the impact of our suggested demand-side changes associated with environmental regulation, we need to compare equations (50)–(53) with the ones in case I of the previous section. If we recall, case I in international competitiveness section shows the effects of higher environmental standards when the regulated firms do not invest in R&D (equations 24-29). To be able to make meaningful comparisons, let us assume that[11] $b_h < b < b_f$. Then, the production of domestic firms will be larger in this case, which incorporates demand side effects of regulation, than in the previous case (from equations 50 and 24). Similarly, foreign production will be relatively smaller due to the incorporation of demand-side changes (from equations 51 and 25). The likeliness of larger domestic profits will be higher with the incorporation of demand-side effects; this can be seen by comparing the four profit expressions in equations (52)-(53) and (28)-(29). Thus, we present an evidence for Porter hypothesis.

Since there is no innovation possibilities in the discussion above, and Porter hypothesis propogates innovation as an instrument for increased competitiveness, this result might not seem so appealing; however, a careful look at our previous analysis in section 5, shows that regulated firms become better-off when they can innovate. If they become better-off after regulation without any innovation due to demand side changes, they will surely be more competitive with innovation and demand side changes. Thus, in addition to the factors listed above, preference for environment-friendly production (i.e., demand-side changes associated with environmental regulation) increases the likeliness of the view of revisionist school.

6 Conclusion

We present some new theoretical results on the debate about the impact of stricter environmental policies on the international competitiveness of the regulated firms. Our study incorporates *tradeable emission permits* as environmental regulation system and this turns out to be an important factor on this debate.

The very notion of trade in emission permits opens up new opportunities and thus abatement and innovation become more attractive for the regulated firms. Our results present

[11] $b_h < b_f$ is already given.

evidences for both conventional school and revisionist school; however, the most interesting result is that the Porter hypothesis is not a theoretical impossibility and moreover, it does not call for extreme assumptions for its validity as suggested by earlier papers in this literature. The frontier that seperates the two school of thoughts on regulation–competitiveness issue not only depends on the properties of innovation process but also depends on the features of the permit market.

Previous research concentrated on the impact of environmental regulation on the supply-side of the economy. We suggest that changes in environmental policies may also affect demand-side of the economy. If consumers have preference for the good that is produced in a relatively cleaner way, then imposition of higher environmental standards at home can increase the demand for domestic production, and thus it opens a road to increased competitiveness. Incorporation of this idea into our model brings further evidence for revisionist school.

7 Appendix

Let us begin with the the problem of each firm. Firms maximize their profits by choosing level of production and abatement; substituting p by $a - b(q_i + q_j)$ in (2):

$$\max_{\mathbf{q_i},\alpha_\mathbf{i}} \quad (a - bq_i - bq_j)q_i - cq_i - e_i(\alpha_i q_i)^2 - P^\epsilon \left(rq_i - \alpha_i q_i - \bar{E}\right) \tag{54}$$

Differentiate (54) with respect to q_i:

$$a - 2bq_i - bq_j - c - 2e_i(\alpha_i)^2 q_i - P^\epsilon(r - \alpha_i) = 0 \tag{55}$$

and with respect to α_i:

$$q_i(-2e_i\alpha_i q_i + P^\epsilon) = 0 \tag{56}$$

From equation (56),

$$A_i = \alpha_i q_i = \frac{P^\epsilon}{2e_i} \tag{57}$$

which is equation (5). Using equation (57) in equation (55), we obtain

$$q_i = \frac{a - c - rP^\epsilon}{2b} - \frac{1}{2}q_j$$

which is the reaction function in (3). Similarly,

$$q_j = \frac{a - c - rP^\epsilon}{2b} - \frac{1}{2}q_i$$

Replacing this in the previous equation, we get the optimal output level in (4).

Proof of Proposition 1:

This requires us to show that profits of the regulated firm in equation (7) is greater than that of the non-regulated firm in (8), i.e.

$$\frac{(a - c - rP^\epsilon)^2}{9b} + \frac{(P^\epsilon)^2}{4e_i} + P^\epsilon \bar{E} \geq \frac{(a - c)^2}{9b} \tag{58}$$

The first term on LHS can be written in an open form,

$$\frac{(a - c)^2}{9b} - \frac{2(a - c)rP^\epsilon}{9b} + \frac{(rP^\epsilon)^2}{9b} + \frac{(P^\epsilon)^2}{4e_i} + P^\epsilon \bar{E} \geq \frac{(a - c)^2}{9b}$$

which implies

$$\frac{r^2 P^\epsilon}{9b} + \frac{P^\epsilon}{4e_i} + \bar{E} \geq \frac{2(a-c)r}{9b} \qquad (59)$$

So if the condition in (59) holds then the firm's profits in the regulated case will be higher than its profit in non-regulated case.

Proof of Proposition 2:

Differentiating (11) with respect to q_2, after replacing p by $a - b(q_1 + q_2)$:

$$a - 2bq_2 - bq_1 - c - 2(\gamma\tilde{e}_2 + (1-\gamma)e_2)(\alpha_2)^2 q_2 - \tilde{P}^\epsilon((\gamma\tilde{r} + (1-\gamma)r) - \alpha_2) = 0 \qquad (60)$$

and with respect to α_2:

$$q_2(-2(\gamma\tilde{e}_2 + (1-\gamma)e_2)\alpha_2 q_2 + \tilde{P}^\epsilon) = 0 \qquad (61)$$

To get the output and abatement levels, we also need to solve for the optimization problem of firm 1; but, this has already been shown above, in the first part of the appendix, as firm 1 does not engage in R&D. Solving equations (55), (56), (60) and (61) together, we get optimal output and abatement levels in equations (12)–(15). Using these values one can get the corresponding profit levels.

Since $\tilde{r} < r$, $\gamma\tilde{r} + (1-\gamma)r < r$, (note that γ is between 0 and 1 since it measures the probability of innovation) and so, $-2(\gamma\tilde{r} + (1-\gamma)r) + r > -2r + (\gamma\tilde{r} + (1-\gamma)r)$, hence, $q_2 > q_1$. Also, since $\gamma\tilde{e}_2 + (1-\gamma)e_2 < e_2$, then $A_2 > A_1$. Using these comparisons in the profit expressions (16) and (17), if we assume that

$$\frac{\left(\tilde{P}^\epsilon\right)^2}{4(\gamma\tilde{e}_2 + (1-\gamma)e_2)} - C_R > \frac{\left(\tilde{P}^\epsilon\right)^2}{4e_1} \quad \longrightarrow$$

$$\left(\tilde{P}^\epsilon\right)^2 \frac{(e_1 - (\gamma\tilde{e}_2 + (1-\gamma)e_2))}{4e_1(\gamma\tilde{e}_2 + (1-\gamma)e_2)} > C_R \ ,$$

then $\pi_2 > \pi_1$. This condition is a sufficient condition, and not a necessary one. It clearly shows that the effect of regulation on the competitiveness of the firms not only depends on the parameters of innovation but also on the features of the permit market, as reflected in permit prices.

Proof of Proposition 3:

Here, we will show the possibility of projects that become feasible and increase the profits of the firm with stricter environmental regulation (and not before the regulation). Assume that before stricter regulation, investment in R&D is not feasible when permit prices are P^{ϵ}, so,

$$\frac{(a-c-2(\gamma\tilde{r}+(1-\gamma)r)P^{\epsilon}+rP^{\epsilon})^2}{9b}+\frac{(P^{\epsilon})^2}{4(\gamma\tilde{e}_2+(1-\gamma)e_2)}+P^{\epsilon}\bar{E}-C_R\leq \frac{(a-c-rP^{\epsilon})^2}{9b}+\frac{(P^{\epsilon})^2}{4e_2}+P^{\epsilon}\bar{E} \qquad (62)$$

After the introduction of stricter environmental regulation, permit prices will increase to $\tilde{P}^{\epsilon}$, and it may change the expected returns to innovation such that the above inequality is reversed:

$$\frac{\left(a-c-2(\gamma\tilde{r}+(1-\gamma)r)\tilde{P}^{\epsilon}+r\tilde{P}^{\epsilon}\right)^2}{9b}+\frac{\left(\tilde{P}^{\epsilon}\right)^2}{4(\gamma\tilde{e}_2+(1-\gamma)e_2)}+\tilde{P}^{\epsilon}\tilde{E}-C_R\geq \frac{\left(a-c-r\tilde{P}^{\epsilon}\right)^2}{9b}+\frac{\left(\tilde{P}^{\epsilon}\right)^2}{4e_i}+\tilde{P}^{\epsilon}\tilde{E} \qquad (63)$$

Since $\tilde{P}^{\epsilon}>P^{\epsilon}$, one can check how the left hand side (LHS) and right hand side (RHS) of the expression in (62) would change due to an increase in permit prices. Let Δ be the difference between LHS and RHS. It can be shown that $\frac{d\Delta}{dP^{\epsilon}}\geq 0$ if $(a-c-2R_EP^{\epsilon})\geq 0$.

Equations (62) and (63) demonstrate that the returns to new projects depend on, among others, permit prices crucially, which will change with the changes in the stringency of the environmental regulation. Thus, projects that were not feasible before, may become feasible with outside changes that are not in the control of the firm.

International Competitiveness:

First, let us try to obtain the optimal output and abatement levels when there are foreign firms competing in the same market with domestic firms. Firm i in the home country solves the following optimization problem:

$$\max_{\mathbf{q_i^H},\alpha_i^{\mathbf{H}}} \quad pq_i^H - cq_i^H - e_i(\alpha_i^H q_i^H)^2 - P^\epsilon\left(rq_i^H - \alpha_i^H q_i^H - \bar{E}\right) \tag{64}$$

where $p = a - b(Q_H + Q_F)$, and $Q_k = q_1^k + q_2^k, \quad k = H, F$. First order conditions result in the following reaction functions:

$$q_i^H = \frac{a - c - rP^\epsilon}{2b} - \frac{1}{2}q_j^H - \frac{1}{2}Q_F \tag{65}$$

The same reaction functions apply in case of foreign firms, and so,

$$q_i^F = \frac{a - c - rP^\epsilon}{2b} - \frac{1}{2}q_j^F - \frac{1}{2}Q_H \tag{66}$$

Using equations (65), (66) and noting that $Q_H = q_1^H + q_2^H$ and $Q_F = q_1^F + q_2^F$, we get

$$q_i^H = q_i^F = \frac{(a - c - rP^\epsilon)}{5b} \tag{67}$$

which is same as equation (21). Abatement levels will be same as closed economy case. Using these results, one can easily obtain profit levels in equation (23).

Proof of Proposition 6:

Both of the domestic firms maximize their expected profits:

$$\max_{\mathbf{q_i^H},\alpha_i^{\mathbf{H}}} \quad \gamma\left[pq_i^H - cq_i^H - \tilde{e}(\alpha_i^H q_i^H)^2 - \tilde{P}^\epsilon\left(\tilde{r}q_i^H - \alpha_i^H q_i^H - \tilde{E}\right) - C_R\right] + \\ (1-\gamma)\left[pq_i^H - cq_i^H - e(\alpha_i^H q_i^H)^2 - \tilde{P}^\epsilon\left(rq_i^H - \alpha_i^H q_i^H - \tilde{E}\right) - C_R\right] \tag{68}$$

Optimization problem of foreign firms is same as above in equation (64). Solving these two optimization problems together we get the optimal output and batement and profit levels given in (30)–(35).

Market shares of the innovating domestic firms and foreign firms are given by equations (30) and (31). Since $R_E\tilde{P}^\epsilon < rP^\epsilon$, then $(2rP^\epsilon - 3R_E\tilde{P}^\epsilon) > (2R_E\tilde{P}^\epsilon - 3rP^\epsilon)$, and so $q_i^H > q_i^F$.

Higher abatement at home country follows from the fact that $\gamma\tilde{e} + (1-\gamma)e < e$; see equations (32) and (33).

The competitiveness will be measured by the changes in the profit levels which we show now.

The first term in the profit expression of domestic firm in (34) is greater than the corresponding term in the profit expression of foreign firms in (35) since they are same as market shares (to the second power). If the cost of R&D satisfies the condition in the proposition, then other terms also become larger in π_i^H than in π_i^F, and so $\pi_i^H > \pi_i^F$. Thus, domestic firms become more competitive after the enactment of stricter environmental regulation. Under given conditions, new profits of domestic firms (equation 34) will exceed their pre-regulation profits (equation 23) since $-rP^\epsilon < (2rP^\epsilon - 3R_E\tilde{P}^\epsilon)$.

Proof of Proposition 7:

In this case, firm 2, the innovating domestic firm, maximizes its expected profits (as in 68) and domestic firm 1 and foreign firms maximize their profits (as in 64). Solving the corresponding first order conditions, we get equations (36)–(44).

Market shares of the innovating domestic firm, firm 1, and the other firms are given by equations (36)–(38). Since $R_E\tilde{P}^\epsilon < rP^\epsilon$, then $(3rP^\epsilon - 4R_E\tilde{P}^\epsilon) > (R_E\tilde{P}^\epsilon - 2rP^\epsilon)$, and so $q_1^H > q_2^H = q_i^F$.

Higher abatement by innovating firm at home country follows from the fact that $\gamma\tilde{e}+(1-\gamma)e < e$ and $\tilde{P}^\epsilon > P^\epsilon$; see equations (39)–(41). Also note that due to higher permit prices at home, non-innovating domestic firm will also abate more than foreign firms (equations (40) and (41)).

The first term in the profit expression of innovating firm in (42) is greater than the corresponding term in the profit expression of the non-innovating domestic firm and foreign firms, equations (43) and (44), respectively, since they are same as market shares (to the second power). If the cost of R&D satisfies the condition in the proposition, then the other terms also become larger in π_1^H than in π_2^H, π_i^F, and so $\pi_1^H > \pi_2^H = \pi_i^F$. Thus, as suggested by Porter, the firm subject to stricter regulation can become more competitive by investing to innovate.

Finally, let us compare the returns to innovation when only one firm innovates versus when both firms innovate. This requires us to compare profits of innovating domestic firm in (42) with (34), profits of domestic firms when they both innovate. Since these expressions only differ in the first terms, we just need to compare the first terms. Again since $R_E\tilde{P}^{\epsilon} < rP^{\epsilon}$, then $(3rP^{\epsilon} - 4R_E\tilde{P}^{\epsilon}) > (2rP^{\epsilon} - 3R_E\tilde{P}^{\epsilon})$, and so π_1^H in (42), which represents the profits of the innovating firm when only one firm innovates, is greater than π_i^H in (34), which represents the profits of the two domestic firms when they both innovate.

References

Albrecht, J.A., 1998, Environmental Costs and Competitiveness. A Product-Specific Test of the Porter Hypothesis, manuscript, www.ssrn.com .

Barrett, S., 1994, Strategic Environmental Policy and International Trade, *Journal of Public Economics*, 54, 325-338.

Jaffe, A.B., S.R. Peterson, P.R. Portney, and R. N. Stavins, 1995, Environmental Regulation and the Competitiveness of US Manufacturing: What Does Evidence Tell Us, *Journal of Economic Literature*, XXXIII, 132-163.

McGuire, M.C., 1982, Regulation, Factor Rewards, and International Trade, *Journal of Public Economics*, 17 (3), 335-54.

Montgomery, W.D., 1972, Markets in Licenses and Efficient Pollution Control, *Journal of Economic Theory*, 5(3), 395-418.

Oates, W. E., K. P. Palmer and P. R. Portney, 1994, Environmental Regulation and International Competitiveness: Thinking About the Porter Hypothesis, Resources for the Future Discussion Paper 94-02.

Palmer, K. P., W. E. Oates, and P. R. Portney, 1995, Tightening Environmental Standards: The Benefit-Cost or No-Cost Paradigm, *Journal of Economic Perspectives*, volume 9, Number 4, 119-132.

Pethig, R., 1975, Pollution, Welfare and Environmental Policy in the Theory of Comparative Advantage, *Journal of Environmental Economics and Management*, 2, 160-69.

Porter, M. A., 1991, America's Green Strategy, *Scientific American*, 168.

Porter, M. A., and C. van der Linde, 1995, Towards a New Conception of the Environment-Competitiveness Relationship, *Journal of Economics Perspectives*, volume 9, Number 4, 97-118.

Sartzetakis, E. S., and C. Constantatos, 1995, Environmental Regulation and International Trade, *Journal of Regulatory Economics*, 8(1), 61-72.

Siebert, H., 1977, Environmental Quality and Gains From Trade, *Kyklos*, 30 (4), 657-73.

Simpson, R. D., and R. L. Bradford, 1996, Taxing Variable Cost: Environmental Regulation as Industrial Policy, *Journal of Environmental Economics and Management*, 30, 282-300.

Xepapadeas, A., and A. De Zeeuw, 1998, Environmental Policy and Competitiveness: The Porter Hypothesis and the Composition of Capital, manuscript, www.ssrn.com .

Yohe, G. W., 1979, The Backward Incidence of Pollution Control-Some Comparative Statics in General Equilibrium, *Journal of Environmental Economics and Management*, 6 (3), 187-98.