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ΘΕΣΣΑΣΛΟΝΙΚΗ, 2005

…στους γονείς μου, Στέλιο και Μαρία.

Ευχαριστώ θερμά τους καθηγητές μου στο Διατμηματικό Πρόγραμμα Μεταπτυχιακών Σπουδών του Πανεπιστημίου Μακεδονίας και ιδιαίτερα τους κ.κ. Χ. Κωνσταντάτο και Ε. Σαρτζετάκη.

CONTENTS

0. Introduction

In the present work we examine the interaction between international trade and the TEP system. We assume an internationally organized TEP market, as the one that the Kyoto Protocol predicts, where national governments take care of the initial distribution. What we are looking for is to see if a country may loose or win in the international competition due to the initial distribution of permits. Economic theory shows that in perfectly competitive markets the initial distribution does not matter. However, in the presence of market frictions the above result is questionable. Could possible market distortions raise strategic considerations for the government? Answers to this question might be extremely useful for already running or future programs of TEP.

Since January of 2005 the European Union has enacted a system of tradeable emission permits for all its state-members, in compliance with the terms of the Kyoto Protocol, thus showing its concern about the global pollution and the climate change. Directive 2003/87/EC of the European Parliament and of the Council, which accepts the Common Position of the state-members, completely describes the implementation of the TEP system. The aim of the European Union is to effectively fulfill the targets of the Kyoto Protocol about pollution reductions. However, the presence of transaction costs raises important problems for countries with no former experience in TEP systems, or of small size, or of heavy bureaucracy. These countries may experience difficulties in establishing an information system that brings together possible permits buyers and sellers. Brokers would undertake this job and brokerage fees will constitute an important part of transaction costs. Could the existence of such costs justify the fear of some politicians that the state-members of the European Union may try to manipulate the international competition *via* the initial permit distribution? Our work aims to shed some light into this question.

Part I consists of three chapters. In chapter 1 we start with the explanation of the strategic effect. Proceeding, we analyze the subject of strategic trade by drawing a baseline model and we outline the corresponding literature. In chapter 2 we present the historical origins as well as a baseline model of Tradeable Emission Permits for perfectly competitive markets. Thereinafter, we present a literature review for market failures in either or in both the product and the permits markets. Finally, in chapter 3 we consider the international dimension of the environmental policy examining the corresponding literature of trade and environment, international environmental agreements, the choice of the environmental regulation, and strategic environmental policy

Part II constitute the theoretical part of this work. In chapter 4 we develop a general model in order to examine the government's strategic considerations on international trade under the environmental regulation of a TEP system and in the presence of transaction costs. Finally, in chapter 5 we examine the completely symmetric case and we conclude some interesting results.

1.STRATEGIC TRADE

1.1 Introduction

In the early 1980's International Trade Theory focused on market structures other than perfect competition or monopoly in order to explain observed patterns of trade such as trade between industrialized countries and intra-industry trade. What became clear was that in imperfectly competitive environments (monopolies or oligopolies) governments have strong incentives to intervene in order to help their firms extract greater profits thus improving domestic social welfare. This strategic behavior on behalf of a government affects not only domestic but also foreign firms. The mechanism wherethrough this effect happens is by affecting firms' marginal cost. That induces the firms to act more or less aggressively compare to the case of non-intervention. The impact of the government's action on firm profits has a *direct effect* and an indirect one called *strategic effect.*

1.2 Strategic effect

To make the notion of *strategic effect* more clear it is convenient to present it in a duopoly framework. Following **Tirole** (1988) let us assume that there are two firms, producing a homogeneous good and competing each other in quantities (Cournot competition). Let

$$(1.2.1)\qquad \Pi_1 = \Pi_1(q_1, q_2)$$

$$(1.2.2)\qquad \Pi_2 = \Pi_2(q_1, q_2)$$

be the duopolists' profit functions. Cournot competition being an one-stage (simultaneous) game implies that one needs to solve firm 1's and 2's first order conditions for q_1, q_2, respectively. The resulting expressions, termed *reaction functions*, constitute a mathematical representation of firm's optimal reactions on its rival optimal choices. Equilibrium quantities are then obtained by solving the system of the resulting reaction functions. Mathematically,

$$(1.2.3)\qquad \left.\begin{aligned} \frac{\partial \Pi_1}{\partial q_1} = 0 \Leftrightarrow R_1 = q_1^{*} = R_1(q_2, x) \\ \frac{\partial \Pi_2}{\partial q_2} = 0 \Leftrightarrow R_2 = q_2^{*} = R_1(q_1, x) \end{aligned}\right\} \Rightarrow \begin{cases} q_1 = q_1^{*}(x) \\ q_2 = q_2^{*}(x) \end{cases},$$

where x is a vector of demand and cost parameters.

Let us assume now that prior to the choice of production level firm 1 has the opportunity to choose the volume of some parameter k. Provided this choice is irrevocable and observed by the rival, it affects production decisions of both firms. The game has now been altered from a simple one-stage game to a two-stage-game and reaction functions are now

$$(1.2.4) \quad \begin{cases} R_1 = q_1^* = R_1[q_2(k), x] \\ R_2 = q_2^* = R_2[q_1(k), x] \end{cases}$$

Once optimal reactions have been determined for all values of k, inserting the above into (1.2.1), and (1.2.2) we get

$$(1.2.5) \quad \Pi_1 = \Pi_1[q_1(k), q_2(k), k]$$

$$(1.2.6) \quad \Pi_2 = \Pi_2[q_1(k), q_2(k), k]$$

Profit functions are now solely functions of k, which affects profit both directly and indirectly through q_1, q_2.

Totally differentiating the above functions and dividing both sides by dk yields

$$(1.2.7) \quad \frac{d\Pi_i}{dk} = \underbrace{\frac{\partial \Pi_i}{\partial q_i}}\frac{dq_i}{dk} + \underbrace{\frac{\partial \Pi_i}{\partial q_{-i}}\frac{dq_{-i}}{dk}} + \underbrace{\frac{\partial \Pi_i}{\partial k}}$$

The first term of the RHS equals zero because of the second stage optimization (envelope theorem). The third term is the direct effect that the choice of k has on the firm's profit, and the second term is the so-called *strategic effect.*

The intuition of the second term is that the firm maximizes profits taking into account that the competitor is going to react optimally subject to the initial choice of k. In the next section we present a simple model of international trade where government's intervention is defined by the strategic effect.

1.3 A baseline model of strategic trade[1]

Assume that n domestic and n_F foreign firms produce a homogeneous good. They compete on quantities (Cournot rivalry) and this competition takes place in a third country's market[2]. The inverse demand function is

[1] The forthcoming analysis follows ch.10 in **Bowen, Hollander and Viaene** (1998).

(1.3.1) $P = P(Q + Q_F)$,

where Q is the domestic and Q_F is the foreign total production respectively. Firms originating from the home country face similar cost functions of the form

(1.3.2) $C(q) = c(q) + F$,

where q the firm's production, $c(q)$ the variable cost and F the fixed cost[3]. Similar equations apply also for the foreign country. Subscript F characterizes foreign country variables.

Assume that governments may intervene by setting a per unit export tax or subsidy, s: positive values of s correspond to subsidization and negative values to taxation. Thus the profit function of a representative firm is

(1.3.3) $\Pi = P(Q + Q_F)q - c(q) + sq - F$

From the maximization of the profit function of both domestic and foreign firms we can take the implicit form of firms' reaction functions corresponding to the first order conditions:

$$(1.3.4) \quad \begin{cases} \dfrac{\partial \Pi}{\partial q} = 0 \Rightarrow P + qP' - c'(q) + s = 0 \\ \dfrac{\partial \Pi_F}{\partial q_F} = 0 \Rightarrow P + q_F P' - c'_F(q_F) + s_F = 0 \end{cases}$$

On the other hand, governments choose their policy taking into account their domestic firms' profits as well as the total cost of their policy. The latter is the amount the government has to pay to (or to receive from) the domestic firms. Thus, they maximize the following welfare function

$$W = n\Pi - sQ \Rightarrow$$

$$(1.3.5) \quad W = P[Q(s, s_F), Q_F(s, s_F)]Q(s, s_F) - nc(\frac{Q(s, s_F)}{n}) - nF$$

with respect to s. Taking first order conditions for the above as well as for the similar welfare function of the foreign government we get

$$(1.3.6) \quad \begin{cases} (P + P'Q - c')\dfrac{\partial Q}{\partial s} + P'Q\dfrac{\partial Q_F}{\partial s} = 0 \\ (P + P'Q_F - c'_F)\dfrac{\partial Q_F}{\partial s_F} + P'Q_F\dfrac{\partial Q}{\partial s_F} = 0 \end{cases}$$

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[2] Competition in third market excludes consumption related dead-weight losses from a government's objective function since they concern foreign consumers. That is only domestic firms' profits have to be taken into account when choosing public policy.

[3] Fixed costs don't matter in our analysis. However, they justify market imperfection.

which correspond to the reaction functions of the domestic and the foreign government respectively. Using equation (1.3.4) the above result can be written as

$$(1.3.7)\quad \begin{cases} [(1-\frac{1}{n})(P'Q-c')-s]\frac{\partial Q}{\partial s}+P'Q\frac{\partial Q_F}{\partial s}=0 \\ [(1-\frac{1}{n_F})(P'Q_F-c'_F)-s_F]\frac{\partial Q_F}{\partial s_F}+P'Q_F\frac{\partial Q}{\partial s_F}=0 \end{cases}$$

Equation (1.3.7) reminds us the strategic effect analysis of the previous section. Notice the absence of direct effect, since government's net revenues exactly cancel out the total change in firms' revenues caused directly from trade policy. We also notice that the second term of the LHS is the already known strategic effect and it is positive[4]. What is different now is that the first term is not equal to zero. This term is another strategic effect arising from the fact that government takes into account the aggregate profits of all its firms. This effect is negative and increasing in n.

1.4 Literature review

Optimal values of s and s_F should also justify equation (1.3.7). That is

$$(1.4.1)\quad \begin{cases} \{(1-\frac{1}{n})[P'Q(s^o,s_F^o)-c']-s^o\}\frac{\partial Q}{\partial s}+P'Q(s^o,s_F^o)\frac{\partial Q_F}{\partial s}=0 \\ \{(1-\frac{1}{n_F})[P'Q_F(s^o,s_F^o)-c'_F]-s_F^o\}\frac{\partial Q_F}{\partial s_F}+P'Q_F(s^o,s_F^o)\frac{\partial Q}{\partial s_F}=0 \end{cases}$$

From (1.4.1) it is clear that the smaller the number of the domestic firms the higher the possibility of exports subsidization (with only one firm the optimal policy always involves a subsidy). This result is in accordance with **Brander and Spencer** (1985), which shows that when one domestic and one foreign firm compete with each other in a third market and the foreign government adopts free trade then the domestic government *"...has a unilateral incentive to offer an export subsidy to the domestic firm"*. It demonstrates that a subsidy on exports raises the market share of the home firm as well as its profits, lowers the profits of the foreign firm, and increases the domestic welfare. It further shows that if both governments intervene, then again the optimal policy depends on the number of domestic firms. If there is only one domestic firm then each government should choose to subsidy exports. However, as the number of its firms is getting larger taxation may be the optimal choice for a government. The reason is that subsidized domestic firm expands its market share not only at the expense of the foreign firms but also at the expense of the rest of the subsidized domestic firms. Hence, the overall gains might be too small in order to overcome the indirect cost of subsidization (*i.e.* the strategic effect that affects the rest of the domestic firms). Finally, it also proves that competition between governments hurts both domestic and foreign welfare in typical "prisoner's dilemma" fashion.

Similarly, **Dixit** (1984), incorporating the home market to the analysis, shows that as the number of the domestic firms is getting larger the government must attenuate the competition between them. The relaxation of the home firms' rivalry increases total profits for a sufficient number of firms. So, the government has the motive to promote mergers and acquisitions and prevent new entry. This can be achieved rather through taxation than through a subsidy on exports. Moreover, **Dixit and Grossman** (1984) proves that in a multi-industry trade regime the subsidization might not be the right choice for a government. It considers a general equilibrium framework where there are many oligopolistic industries competing for the services of a specific factor. In this case the subsidization of an industry may have as a result not the profit shifting from foreign to domestic country but the extraction of other domestic industries' rents. It finds that for specific market and cost parameters free trade or even taxation of exports might be the optimal policy.

Extending the analysis of optimal trade policy **Eaton and Grossman** (1986) examines different forms and conducts of rivalry. It shows that, contrary to the case of Cournot competition between domestic and foreign firms where subsidization is the optimal policy, in a Bertrant rivalry the optimal policy involves export taxation. Moreover, in a duopoly context and for consistent conjectural variations free trade is optimal[5]. Finally, following an alternative approach **Krugman** (1984) shows that in the presence of economies of scale import protection might lead to profit shifting thus improving domestic welfare[6]. The intuition is that protecting a domestic industry allows the domestic firms to grow. Since there are economies of scale, larger firms will have lower marginal costs. Thus, in some cases, the savings in social welfare because of more efficient production could be greater than the losses because of the relaxation of rivalry.

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[4] It can be easily shown that $\partial Q/\partial s > 0$, $\partial Q_F/\partial s_F > 0$, $\partial Q/\partial s_F < 0$, and $\partial Q_F/\partial s < 0$.

[5] As it says, optimal policy *"...depends on whether home firm's output in the laissez-faire equilibrium exceeds or falls short of the level that would emerge under consistent or Stackelberg conjectures"*.

[6] Many development theories, naming import substitution industrialization theories, were built in early '70 based in similar frameworks.

2. TRADEABLE EMISSION PERMITS

2.1 Theoretical origins

A typical case of market failure is that of external economies or, for simplicity, externalities. Sometimes the economic activity of an agent indirectly hurts or benefits others. That makes the allocation of resources through the price mechanism inefficient since it underestimates (or overestimates) the cost of such externalities generating activities. Following **Pigou** (1920), for many years the only cure economic theory could propose to the problem of externality was taxation. Pigou himself argues that we should impose a tax (subsidy) on activities that cause negative (positive) external effects. In order to have full internalizations of the external effects this tax (subsidy) must be equal to the marginal social damage (benefit) that these activities generate. However, **Coase** (1960) argues that such an intervention may not only be problematic in terms of applicability, but also inequitable. It suggests that instead of taxation, a solution can be reached through the market. All is needed is a well-established system of transferable property rights. In environmental cases we could think of someone having the right to pollute or someone else having the right to a clear ambience. Under such a regime they could bargain inter se, and price mechanism would yield the optimal solution.

In the late '60, **Thomas D. Crocker** (1966) and **J.H. Dales** (1968) place the theoretical foundations of a transferable property rights system oriented in environmental issues. The first shows how we could apply such a system in the case of air pollution[7] while the second points out how the same could be done in water pollution cases. Despite the lack of a mathematical model, Crocker and Dales manage to give the intuition behind this subject and cover a broad range of contiguous issues. Few years later, **Baumol and Oates** (1971) sets the necessary mathematic background. It proves that, if both the product and the permits market are perfectly competitive then the tradeable permits system achieves the objective of pollution control in a cost-effective manner. Moreover, under the same assumptions this cost effectiveness is independent of the initial allocation of permits as sown in **Montgomery** (1972). In the next section we present a baseline model. Comparing tradeable emission permits (TEP) framework with the benchmark case of the "social planner" we verify the properties mentioned above.

[7] It is interesting for someone to read the introduction of T.Crocker's paper in order to have an idea of how environmental issues have been evolved over time.

2.2 A baseline model of TEP

Following **Xepapadeas** (1997) let i's firm emission generation process be

$$(2.2.1)\; e_i = s_i(q_i, a_i),$$

where $i = 1,...,n$ is the number of the firms, q_i and a_i are i's firm production level and abatement effort, respectively, with $\partial s_i/\partial q_i > 0$, and $\partial s_i/\partial \alpha_i < 0$. The economy's total amount of the generated emissions is

$$(2.2.2)\; E = \sum_{i=1}^{n} e_i$$

Assuming a well defined social cost function of the form

$$(2.2.3)\; D = D(E),$$

where E defined as above with $\partial D/\partial E > 0$ and $\partial^2 D/\partial E^2 > 0$, a social planner has to maximize the difference between society's surplus (*i.e.* firms' profits and consumers' surplus) and social cost. Assuming that the firms face cost functions of the form

$$(2.2.4)\; c_i = c_i(q_i, \alpha_i)$$

where $\partial c_i/\partial q_i > 0$, $\partial c_i/\partial \alpha_i > 0$, and defining the inverse demand function as

$$(2.2.5)\; P = P(Q),$$

where $Q = \sum_{i=1}^{n} q_i$ with $\partial P/\partial Q < 0$, the social planner's maximization problem can be written as

$$(2.2.6)\; \max_{q,a} SW = \int_0^Q P(Q)dQ - \sum_{i=1}^{n} c_i(q_i, \alpha_i) - D(E)$$

First order conditions to the above problem are

$$(2.2.7)\; \begin{cases} P - \partial c_i/\partial q_i - D'(E)\,\partial s_i/\partial q_i = 0 \\ -\partial c_i/\partial \alpha_i - D'(E)\,\partial s_i/\partial \alpha_i = 0 \end{cases}$$

Assume now that the government decides a maximum on the overall emissions level, $\bar{E}$,[8] and issues a number of permits each one of them corresponding to specific amount of emissions. After that, the government allocates the permits to the pollutants[9]. So, we define the allocation of permits as

$$(2.2.8)\; \bar{e} = [\bar{e}_1, ..., \bar{e}_n],$$

[8] We examine only the interesting case were the environmental standards imposed by the government are stricter than the environmental effects of the free trade equilibrium.

[9] For a brief analysis of initial allocation patterns one can see the introduction of **Tietenberg** (2001).

with $\overline{E}=\sum_{i=1}^{n}\overline{e}_i$, where $\overline{e}_i$ is the initial allocated amount of permits to the i firm. Firms are able in a next stage to exchange these permits in a permits market. Let us define i's firm net demand for permits (NDP) as

$$(2.2.9)\ NDP = P^E(e_i-\overline{e}_i),$$

where P^E is permits price. In order to conform to the environmental standards posed by the government firms have the options to *a)* reduce their production q, *b)* increase abatement α and *c)* participate in a secondary market for permits. Assuming for convenience that the permits market is perfectly competitive, firms have to maximize the following profit function

$$(2.2.10)\ \max_{q,\alpha}\Pi_i = Pq_i - c_i(q_i,\alpha_i) - P^E[s_i(q_i,\alpha_i)-\overline{e}_i]$$

First order conditions are

$$(2.2.11)\begin{cases} P-\partial c_i/\partial q_i - P^E\,\partial s_i/\partial q_i = 0 \\ -\partial c_i/\partial \alpha_i - P^E\,\partial s_i/\partial \alpha_i = 0 \end{cases}$$

Finally, the summation of (2.2.9) for all is by definition is zero, and combining this with (2.2.8) yields

$$(2.2.12)\ \sum_{i=1}^{n}s(q_i,a_i)-\overline{E}=0$$

Equations (2.2.11) and (2.2.12) completely define this model since they yield the optimal values of P^E, q_i and α_i. Comparing equation (2.2.11) with (2.2.7) we find that when permit price equals marginal social cost, social optimum is achieved. Moreover, the exclusion of any friction from the markets means that this social optimum is achieved in a cost effective manner. Finally, the absence of the initial share of permits from the first order conditions defined in equation (2.2.11) shows that the optimality is achieved irrespectively of initial permit allocation.

2.2.3 TEP and market frictions

The hypothesis of perfect market conditions is rather unrealistic. There are various reasons why the markets might not operate perfectly: firms with market power in either the permits or the product market; transaction costs; market and regulatory uncertainty. Empirical studies (among others **Owen *et al.*** 1992, **Atkinson and Tietenberg** 1991, **Hahn and Hester** 1989) support the above argument. Hence, the model described in the previous section may need serious modifications in order to describe many of the real world situations.

There is a plethora of research work concerning these matters. **Hahn** (1984), for example, uses a dominant firm framework *"...to explore how the initial distribution of property rights can lead to inefficiencies"*. It proves that the distribution of permits has to do not only with equity issues (i.e. being a wealth transfer device) but also with efficiency. In his model, fringe firms that are price takers still have the optimization problem given in (2.2.10) and the corresponding FOC's given in (2.2.11). Things are different now for the dominant firm: it has the power to manipulate permit price in order to extract greater profits. This manipulation is achieved through the abatement effort of the firm[10]. However, this power is not boundless, depending on the total amount of permits issued by the government. Profit maximization problem for the dominant firm takes the form

$$(2.3.1)\quad \max \Pi_i = Pq_i - c_i[q_i, \alpha_i(P^E)] - P^E\{s_i[q_i, \alpha_i(P^E)] - \bar{e}_i\}$$

$$\text{s.t.}\quad s_i = \bar{E} - \sum_{\substack{j\neq i\\ j=1}}^{n-1} s_j[q_j, \alpha_j(P^E)]$$

The corresponding FOC's are now

$$(2.3.2)\begin{cases} P - \partial c_i/\partial q_i = 0 \\ -[(\partial c_i/\partial \alpha_i)(\partial \alpha_i/\partial P^E) - P^E]\sum(\partial s_j/\partial \alpha_j)(\partial \alpha_j/\partial P^E) - [\bar{E} - \sum s_j - \bar{e}_j] = 0 \end{cases}$$

From the comparison of equations (2.2.11) and (2.3.2) it follows immediately that the only case where there is equalization of marginal abatement costs across the firms is when the dominant firm's initial share of permits has the exact amount that firm will use in equilibrium, *i.e.* $\bar{E} - \sum s_j - \bar{e}_i = 0$. In any other case inefficiency increases as the allocation of permits diverge from such a point because *"...the total expenditure on abatement will exceed the cost-minimizing solution"*.

Fershtman and de Zeeuw (1995) considers a duopoly where two firms compete each other in both the product and the permits market. The main point of that paper is that in some cases the firms can use the trade of permits as a credible commitment for collusion behavior resulting in manipulation of production level and increased joint profits. Under the simplifying assumption of symmetric linear production costs Fershtman and de Zeeuw (1995) classifies this manipulation.

Starting from very loose emission standards, *i.e.* permits are non-binding constraints for either firms and they have no reason to abate, where the firms trade the permits only in order to affect production level it is shown that: *a)* product prices are higher, *b)* output level is lower, and *c)* pollution level is lower, relative to the case where permits are not tradeable. On the other hand, there is the case of very strict emission standards, *i.e.* permits are binding constraint for both firms, where there is no connection between the two markets. In this case the firm with the lower marginal abatement cost sells all its permits to the firm with the higher marginal abatement cost thus ensuring the cost-efficiency of abatement effort. Between these two benchmark cases lie an infinite number of intermediate cases, depending on parameter values of the emission generating process and of the abatement costs.

In a similar context, **Sartzetakis** (1997) considers the possibility of raising rival's cost through the permits market. Its benchmark case, where both firms are price takers in permits market but they are engaged in Cournot competition in products market, is characterized by minimized abatement cost and overall inefficiency.[11] In addition, overall efficiency is not affected by the initial allocation of permits, which touches only equity issues. If, however, one firm (the "leader") has control over the permits price, it may use this power in order to raise the marginal cost of its opponent. Despite the fact that increasing the price of permits does increase the leader's marginal cost as well, the impact on the follower's marginal cost is larger. As a result, the leader gains market share at the expense of the follower. This is an example of the presence of a strategic effect. Using simulations, **Sartzetakis** (1997) shows that:

- Industry's output is decreased.
- The leader firm always increases its profits.
- Total industry profits are increased (reduced) if the leader (follower) is more efficient in production than the follower (leader) and the follower (leader) is more efficient in abatement.

Stavins (1995) incorporates transaction cost in the analysis of TEP. It examines how, in the presence of such costs (additional to any other existing production and/or abatement costs), firms change their choices over production level

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[10] That makes total abatement a function of permit price.

[11] That is because the "regulator" is trying to correct two problems (environmental externalities and products market imperfection) having only one "tool" (permits) available.

and abatement effort, thus altering permits' volume of trade. Profit maximization is now

(2.3.3) $\max \Pi_i = Pq_i - c_i(q_i,\alpha_i) - P^E[s_i(q_i,\alpha_i) - \bar{e}_i] - T(t_i)$,

where $t_i = |s_i(q_i,\alpha_i) - \bar{e}_i|$ is i's firm NDP, and $T(t_i)$ is its transaction cost. The corresponding FOC are

(2.3.4a) $\begin{cases} P - \partial c_i/\partial q_i - [P^E + T'(t_i)]\,\partial s_i/\partial q_i = 0 \\ -\partial c_i/\partial \alpha_i - [P^E + T'(t_i)]\,\partial s_i/\partial \alpha_i = 0 \end{cases}$, if $NDP > 0$

or

(2.3.4b) $\begin{cases} P - \partial c_i/\partial q_i - [P^E - T'(t_i)]\partial s_i/\partial q_i = 0 \\ -\partial c_i/\partial \alpha_i - [P^E - T'(t_i)]\partial s_i/\partial \alpha_i = 0 \end{cases}$, if $NDP \le 0$

Assume a duopoly where, if any trade in permits is conducted, one firm, say firm 1, is buyer of permits while firm 2 is seller of permits. Hence, the following is true

(2.3.5) $\partial c_1/\partial \alpha_1 + P^E\,\partial s_1/\partial \alpha_1 + T'(t_i)\partial s_i/\partial \alpha_i = \partial c_2/\partial \alpha_2 + P^E\,\partial s_2/\partial \alpha_2 - T'(t_i)\partial s_2/\partial \alpha_2$

It is clear that, in the presence of transaction cost, tradeable permits do not lead to equalization of marginal abatement costs across firms but to equalization of the sums of marginal abatement costs and marginal transaction costs. Hence, the result is an inefficient allocation of resources on abatement efforts.

Moreover, comparative-static analysis results in

(2.3.6) $\dfrac{ds_i}{d\bar{e}_i} = A \times T''(t_i)$,

where $A < 0$. Therefore the sign of $ds_i/d\bar{e}_i$ depends on marginal transaction cost: s_i and $\bar{e}_i$ are positively (negatively) correlated if MTC is decreasing (increasing) and they are uncorrelated if MTC is constant. In other words for non-constant MTC the initial allocation of permits affects the equilibrium choices of the firms.

Finally, **Montero** (1997) extends Stavin's work and includes uncertainty besides transaction cost. Motivated from many already established pollution control programs, where regulatory restrictions and administrative requirements result in uncertainty about permits' trade approval, this paper builds up both a theoretical model and a numerical example. Examining the effects of uncertainty on efficiency it finds that marginal abatement costs are not equalised across firms. Actually, marginal abatement costs of permit buyers are higher than those of sellers and the equilibrium with uncertainty and transaction cost draws away from the cost-effective point. Relatively to the effects of the initial allocation of permits on the equilibrium its findings are close to Stavin's conclusions. However, its numerical example reveals a rather surprising feature: even in the case of certainty and constant marginal transaction cost, the initial allocation matters! According to the author this can be explained by the discontinuity of marginal abatement cost function along with the indivisibility of permits.

3.INTERNATIONAL DIMENSION OF ENVIRONMENTAL POLICY[12]

3.1 Introduction

Quite naturally, a large part of environmental policy is closely related to international trade issues, since there is a strong link between them. First, there is the matter of pollutants that cause harm to interstate or even global natural resources (*e.g.* rivers that flow through different countries, sea's international waters, the atmosphere etc.) and the need to mitigate this harm through environmental agreements between the concerning countries. Such agreements indirectly affect the patterns of trade by fundamentally altering both the demand and the supply side. Second, the issues of environmental protection should nowadays be examined under the scope of economy's globalization: since the late 1950's many trade blocs have been established (*e.g.* OECD, EEC, NAFTA, and COMECON) besides the always increasing number of bilateral or multilateral trade agreements[13]. In such a framework the close relationship of international trade and environmental policy can be easily seen as being bidirectional.

In the rest of this chapter we will try to outline the literature that has been developed during the past years. We will focus only to those papers that analyze different aspects of strategic environmental policies.

3.2 Trade and environment

An issue that has drawn much attention among researchers is the openness of different economies to trade and its effects on the environment. The questions usually posed in this case are: a)*"is free trade good for the environment?"*, b) *"do the dirty industries migrate?"*, and c)*"how the gains or the losses from trade are distributed among the countries?"*. Unfortunately, the answers to these questions tend to be model specific, with only a few general results being available. **Copeland and Taylor** (1994), using a North-South trade model where differences in pollution taxes are the only motivation for trade, finds that under free trade overall pollution increases and

[12] This title is borrowed from ch.6 in **Xepapadeas'** "Advanced principles of environmental economics" (1997).

there is eco-dumping: The richer North is specialized in the production of the "cleaner" goods while the poor South produces the "dirty" ones. In a similar trade model **Chichilnisky** (1994) shows that when the differences in the property rights regime lead to trade, the overall pollution increases and the North gains at the expense of the South. On the contrary, **Antweiler *et al.*** (1998), decomposes the impact of trade on the environment into scale, technique and composition effects[14]. After using empirical data to estimate those components, it concludes that free trade benefits the environment. Similarly, **Copeland and Taylor** (2005) show that overall pollution might be decreased if the rich North unilaterally reduces its emissions. The intuition is that domestic and foreign emissions are strategic substitutes and the substitutability effect sometimes outmatches the income and free riding effect. Moreover, the analysis in **Copeland** (2000) offers a taxonomy of the non-cooperative game between the governments and can be used in order to verify how the gains from trade are distributed among countries and what happens to the overall emission level.

3.3 International environmental agreements

Another direction that economic research took during the past decade is analyzing international environmental agreements (IEA). The principal questions are a)*"why some countries sign an IEA while others do not?"*, b) *"must the deniers be threaded or subsidized in order to sign in"*, and most important c) *"under what conditions is an IEA stable?"*. Most of the researchers follow **d'Aspremont *et al.*** (1983) by examining the stability of an IEA as a cartel coalition. Their findings are rather disappointing: **Botteon and Carraro** (1997), **Diamantoudi and Sartzetakis** (2001), and **Carraro and Marchiori** (2003), among others find that large coalitions are not stable and the number of the participants is too small (not more than four). However, this result does not completely describe reality: IEA are usually signed from more countries. In order to overcome this inconsistency economists incorporate to their analysis monetary or technology transfers (**Botteon and Carraro,** 1997), issue linkages (**Carraro**, 1999), repeated game framework (**Barrett**, 1994b), theory

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[13] There are more than 2000 registered bilateral or multilateral environmental agreements according to IEA database (http://darkwing.uoregon.edu/~iea/).

[14] This method is also followed from **Grossman and Krueger** (1993), and **Copeland and Taylor** (1994,1995). The decomposition refers to the effect on the ambience because of the increased economic activity, the use of cleaner production methods, and the change of final product composition correspondingly.

of social situations (**Wietze and Tol**, 2004). Nevertheless, the IEA is of great interest and economists still work expanding their research in this field.

3.4 International trade and the choice of environmental policy instrument

A field of special interest is that of the choice of environmental policy: should a government impose emission taxes or should it trust the market mechanism and issue tradeable permits? Using a two-stage Cournot duopoly model, that allows taking into account strategic interaction, **Ulph** (1992) proves that it is in the best interest for both the domestic and the foreign country to protect the environment by imposing a ceiling on the overall emissions rather than using taxation. Such a policy discourages over-investment, thus ensuring lower production and higher profits[15].

Sartzetakis and Constantatos (1995) proves that, if the permits market is competitive, TEP is preferable to any "command and control" (CAC) regulation (e.g. emission standards) in trade-open oligopolistic economies. Necessary and sufficient condition for this to be true is that the abatement technology across firms within the same country differs. If this is the case, TEP better allocates abatement effort among firms. This in turn results in better positioning of country's firms in the international competition. However if there is a distortion in the permits market this result is weakened and sometimes even inverted.

On the other hand, **Boom** (2003a, 2003b) shows that, while permit trading is welfare improving when all the markets are competitive, in the presence of imperfect competition a system based on relative standards should be implemented. The intuition behind this result is simple: TEP system efficiently allocates abatement effort among firms thus giving them a cost advantage in the market. On the other hand, a relative standards system gives firms a positioning advantage by allowing them to produce more. In competitive markets, the positioning advantage has no meaning but in oligopolistic markets this advantage is greater than the cost advantage.

Finally, using a general equilibrium model, **Copeland and Taylor** (2005) shows that uniform reductions in emissions can be efficient while TEP may make both countries worse-off. This is due to the effect that the implementation of TEP has on the terms of trade for goods as well as the effect it may have on the choices of

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[15] This is the typical result of **Brander and Spencer** (1985).

other countries' emission ceilings. Copeland and Taylor prove that under specific conditions, these effects might overcome the direct gain from the TEP regulatory regime.

3.5 International trade and strategic environmental policy

Many of the aforementioned results follow immediately once strategic considerations of environmental policy are taken into account. Although there were many earlier papers that touch this subject[16] it was not until **Barrett** (1994a) that strategic interactions between international trade and environmental policy were formally introduced to the environmental economics literature. In the next section we present a simple model of strategic environmental policy.

Assume, as in the model described in the first section, that there are n domestic and n^F foreign firms. They compete on quantities and this competition takes place in a third country's market. There are also a domestic and a foreign government that choose their environmental policies by setting emission standards. Using the same notation as before let

$$(3.5.1)\quad R^i = R^i(q^i, q^{-i}, q^F),$$

$$(3.5.2)\quad C^i = C^i(q^i),$$

$$(3.5.3)\quad A^i = A^i(q^i, e^i),$$

be i firm's revenue, production cost, and abatement cost functions respectively. Thus firm i maximizes

$$(3.5.4)\quad \max_{q^i} \Pi^i = R^i(q^i, q^{-i}, q^F) - C^i(q^i) - A^i(q^i, e^i),$$

and the corresponding FOC is

$$(3.5.5)\quad \frac{\partial \Pi^i}{\partial q^i} = \frac{\partial R^i}{\partial q^i} - \frac{\partial C^i}{\partial q^i} - \frac{\partial A^i}{\partial q^i} = 0$$

The domestic government's welfare problem is

$$(3.5.6)\quad \max_{E} W = \sum_{i=1}^{n} \Pi^i(q^i, q^{-i}, q^F, e^i) - D(E),$$

where $E = \sum_{i=1}^{n} e_i$, and the corresponding FOC is

$$(3.5.7)\quad \frac{1}{n}\left[\sum_{i=1}^{n} \frac{\partial \Pi^i}{\partial e^i} + \sum_{i=1}^{n} \frac{\partial \Pi^i}{\partial q^i}\frac{\partial q^i}{\partial e^i} + \sum_{i=1}^{n} \frac{\partial \Pi^i}{\partial q^F}\frac{dq^F}{dq^i}\frac{dq^i}{de^i} + \sum_{i=1}^{n}\sum_{\substack{j=1 \\ j\neq i}}^{n-1} \frac{\partial \Pi^i}{\partial q^j}\frac{dq^j}{de^j}\right] - \frac{\partial D}{\partial E} = 0$$

[16] See for example **Markusen** (1975), **Krutilla** (1991), and **Ulph** (1992).

From (3.5.7) and assuming that government chooses E prior to firms' decisions we get

$$(3.5.7a)\quad \frac{1}{n}\Big[\sum_{i=1}^{n}\frac{\partial\Pi^i}{\partial e^i}+\sum_{i=1}^{n}\frac{\partial\Pi^i}{\partial q^F}\frac{dq^F}{dq^i}\frac{dq^i}{de^i}+\sum_{i=1}^{n}\sum_{\substack{j=1\\ j\neq i}}^{n-1}\frac{\partial\Pi^i}{\partial q^j}\frac{dq^j}{de^i}\Big]-\frac{\partial D}{\partial E}=0,$$

if the government acts strategically which reduces to

$$(3.5.7b)\quad \frac{1}{n}\sum_{i=1}^{n}\frac{\partial\Pi^i}{\partial e^i}-\frac{\partial D}{\partial E}=0,$$

if the government does not act strategically. The first term of equation (3.5.7a) is the direct effect of government's policy on firms' profits, while the second and the third terms are strategic effects. The second effect is internationally oriented and it is positive while the third effect is domestically oriented and it is negative.

Barrett (1994) names government's policy defined from (3.5.7a) as environmentally optimal emission standards (EOS) and the policy defined from (3.5.7b) as strategically optimal emission standards (SOS). It shows that if there is only one domestic firm, emission limits set according to SOS are higher than those set according to EOS.[17] By allowing its firms to pollute more, domestic government indirectly subsidies them and induces them to produce more. If the domestic government is the only one that acts strategically, it succeed in expanding domestic firm's market share in the international market at foreign country's expense. Thus domestic government has strong incentives to unilaterally adopt SOS. If both governments act strategically (i.e. we solve the system of (3.5.7b) and of its respective equation for the foreign government to find optimal values of E and E^F) then compared to the case of EOS they overproduce. Even if both countries are worse-off under SOS, neither government has incentive to change its policy.

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[17] To see this, note that in the case of a single firm, (3.5.7a) and (3.5.7b) are reduced to

$$\frac{\partial\Pi}{\partial q}\frac{\partial q}{\partial E}+\frac{\partial\Pi}{\partial E}-\frac{\partial D}{\partial E}=0,$$

and

$$\frac{\partial\Pi}{\partial E}-\frac{\partial D}{\partial E}=0$$

Therefore, under SOS, marginal social damage is set equal to a term that is higher than marginal abatement cost. We also know that $\partial D/\partial E>0$ and $\partial^2 D/\partial E^2>0$. Thus, $e_{SOS}\geq e_{EOS}$.

In the case of domestic oligopoly things are more complicated: SOS may be weaker (lower emission standards) or stronger (higher emission standards) than the EOS. Depending on the difference between the second and the third term of (3.5.7b). If the former is greater than the latter, then SOS is weaker than the EOS and vice-versa. Finally, Barrett shows that, independently of the structure of the domestic and the foreign industries and no matter if both governments act strategically, under Bertrant competition SOS is always stronger than EOS.

Examining the subject of ecological dumping and using partial equilibrium analysis, **Rauscher** (1994) confirms the result of **Barrett** (1994) and perceives these results as a good explanation for industries' migration. However, taking into account the general equilibrium effects it shows that the above conclusions might be dramatically altered: Assuming the existence of two production sectors where the one produces non-tradeable goods while the other produces exported goods, it shows that there are two opposite forces that affect capital movement. The looseness of its environmental standards makes a sector more productive and draws capital while the resulting decrease in the good's price expels capital. If this is the case for the exported good sector the former always cancel-out the latter and there is no eco-dumping. Moreover, it is possible for looseness to take place on the other sector too (i.e. if the overall result on capital movement due to the laxity of standards is negative for this sector) in order to attract more capital to the export-oriented sector. Such a policy is exactly the opposite of environmental dumping.

Ulph (1996) uses a similar model to describe and compare two environmental policies: emission standards and environmental taxes. It considers an international duopoly framework and allows firms to behave strategically. That is prior to their choice of how much to produce, firms have the opportunity to choose the level of a capacity parameter, ϕ, that could be, for instance, R&D expenses aiming to lower production cost. Therefore a firm maximizes

$$(3.5.8)\ \max_{q} \Pi = R(q,q^F) - C(q,\phi) - K(\phi) - A(q,E),$$

where K is the R&D cost function, $\partial K/\partial\phi > 0$, and $\partial C/\partial\phi < 0$. The corresponding FOC is given again by equation (3.5.5) ignoring the superscripts. If the firm does not behave strategically, it chooses ϕ to minimize production and R&D cost, thus yielding

(3.5.9) $\dfrac{\partial C}{\partial \phi}+\dfrac{\partial K}{\partial \phi}=0$

On the other hand, if the firm behaves strategically, it chooses ϕ to maximize (3.5.8) yielding

(3.5.10) $\dfrac{\partial R}{\partial q^F}\dfrac{\partial q^F}{\partial \phi}-\dfrac{\partial C}{\partial \phi}-\dfrac{\partial K}{\partial \phi}=0$,

where the first term (i.e. the strategic effect) is positive. Comparing (3.5.9) and (3.5.10) it is easy to verify that ϕ is greater when the firm acts strategically. Ulph proves that when both firms act strategically, overall output and emissions are higher compared to the case of no strategic considerations. Finally, it examines the case where both sides, governments and producers, act strategically. This corresponds to a three-stage game where at the first stage both governments choose simultaneously their emission standards. At the second and the third stage firms are choosing their R&D and production levels, correspondingly. First order conditions at the third stage and the corresponding reaction functions are

(3.5.11) $\left\{\begin{matrix} \dfrac{\partial R}{\partial q}-\dfrac{\partial C}{\partial q}-\dfrac{\partial A}{\partial q}=0 \\ \dfrac{\partial R^F}{\partial q^F}-\dfrac{\partial C^F}{\partial q^F}-\dfrac{\partial A^F}{\partial q^F} \end{matrix}\right\} \Rightarrow \begin{cases} q^* = q^*\left[q^F[\phi(E,E^F),\phi^F(E,E^F)]\right] \\ q^{F*} = q^{F*}\left[q[\phi(E,E^F),\phi^F(E,E^F)]\right] \end{cases}$

Solving the above system defines the optimal production levels, $\hat{q}$ and $\hat{q}^F$. Substituting back into (3.5.8) and taking first order conditions, yields

(3.5.12) $\left\{\begin{matrix} \dfrac{\partial R}{\partial q}\dfrac{\partial q}{\partial \phi}-\dfrac{\partial C}{\partial \phi}-\dfrac{\partial K}{\partial \phi}-\dfrac{\partial A}{\partial \phi}=0 \\ \dfrac{\partial R^F}{\partial q^F}\dfrac{\partial q^F}{\partial \phi^F}-\dfrac{\partial C^F}{\partial \phi^F}-\dfrac{\partial K^F}{\partial \phi^F}-\dfrac{\partial A^F}{\partial \phi^F} \end{matrix}\right\} \Rightarrow \begin{cases} \phi^* = \phi^*[\phi^F(E,E^F)] \\ \phi^{F*} = \phi^{F*}[\phi(E,E^F)] \end{cases}$

Solving the above system defines the optimal R&D levels, $\hat{\phi}$ and $\hat{\phi}^F$. Finally, substituting back into governments' welfare maximization problem yields

(3.5.13) $\left.\begin{matrix} \dfrac{\partial \Pi}{\partial q^F}\dfrac{\partial q^F}{\partial E}+\dfrac{\partial \Pi}{\partial \phi^F}\dfrac{\partial \phi^F}{\partial E}+\dfrac{\partial \Pi}{\partial E}-\dfrac{\partial D}{\partial E} \\ \dfrac{\partial \Pi^F}{\partial q}\dfrac{\partial q}{\partial E^F}+\dfrac{\partial \Pi^F}{\partial \phi}\dfrac{\partial \phi}{\partial E^F}+\dfrac{\partial \Pi^F}{\partial E^F}-\dfrac{\partial D^F}{\partial E^F} \end{matrix}\right\} \Rightarrow \begin{cases} E^* = E^*(E^F) \\ E^{F*} = E^{F*}(E) \end{cases},$

The solution of the above system defines the optimal emission standard, $\hat{E}$ and $\hat{E}^F$.

Ulph uses a similar model in order to analyze the use of emission taxes instead of emission standards. It proves that *a)* emission standards are more efficient than emission taxes when governments and producers act strategically, *b)* both countries are worse-off if both the governments and the producers act strategically compared to the case where only the governments or the producers act strategically, and, finally, *c)* while strategic behavior of firms reduces without eliminating the governments' incentive to relax their environmental policy, strategic behavior of governments always reverses firms incentives, leading them to overinvest in R&D.

4. THE MODEL

4.1 Assumptions and basic functions

Let us assume that there are two domestic firms, firms 1 and 2, and one foreign firm, firm 3, producing a homogeneous good that is sold exclusively in a third market.[18] Firms compete in quantities (Cournot competition). Let the inverse demand function of the third country be

(4.1.1) $P = A - (Q + q_3)$,

where $Q = \sum_{i=1}^{2} q_i$ is the aggregate level of domestic production, and q_3 is the foreign firm's production. The production process discharges pollutants to the ambiance. Pollutants are generated according to

(4.1.2) $e_i = \rho_i q_i$,

where $i = 1,2,3$.[19] Thus, the total amount of pollutants that a country emits is given by

(4.1.3) $E = \sum_{i=1}^{n} e_i$

Moreover, assume that there is an abatement technology available to all firms. Thus, we can define i firm's abatement effort as

(4.1.4) $A_i = \alpha_i q_i$,

where α_i is the level of abatement per unit of product. Let i firm's abatement cost function be

(4.1.5) $AC_i = \frac{1}{2}\varepsilon_i(\alpha_i q_i)^2$,

where ε_i is a firm-specific parameter of technology. Since abatement is costly, firms will choose zero abatement in the absence of policy intervention. However, pollutants are a public bad causing negative effects on social welfare.[20] Therefore, governments may intervene in order to mitigate this problem by imposing a country-specific ceiling, $\overline{E}$, on the overall level of emissions. We assume that the setting of $\overline{E}$ is not

[18] For the assumption of the third market see footnote 2.

[19] Similar equations also apply for the foreign country just using an asterisk as a superscript whenever is needed.

[20] See, for example, equation (2.2.3) that incorporates social damage as a function of the total emissions into the social welfare function.

subject to strategic considerations, therefore, $\overline{E}$ will be treated as exogenous.[21] Hereafter, each government issues a number of permits, each one of them corresponding to specific amount of emissions, and distributes them free-of-charge to the firms.

We consider a two-stage game, where in the first stage the government allocates the permits, while in the second stage firms choose their production levels. The initial permits allocation in the home country is defined as

$$(4.1.6)\ \overline{e} = [\overline{e}_1, \overline{e}_2],$$

where $\overline{e}_i$ is the amount of permits initially allocated to the i firm and $\overline{E} = \sum_{i=1}^{2} \overline{e}_i$. Hence, firms face an environmental constraint of the form

$$(4.1.7)\ e_i - A_i = \overline{e}_i$$

Following the initial distribution of permits, firms could trade permits in a permits market. This market is assumed to be internationally organized and perfectly competitive since a sufficient number of firms participate in it. Hence, the price of a permit is exogenous in our analysis. We define i firm's net demand for permits as

$$(4.1.8)\ NDP_i = (e_i - A_i - \overline{e}_i),$$

Furthermore, all firms face a production cost of the form

$$(4.1.9)\ C_i = c_i q_i,$$

where c_i is i firm's constant marginal production cost.

Finally, we assume that firms face transaction costs when they participate in the permits market. These costs might be the result of *a)* the small size of the local permits market, *b)* administrative costs for entering the international market, or *c)* additional administrative constraints that a government might induce. The transaction cost might represent brokerage fees that both a permits seller and a permits buyer have to pay,[22] and is assumed to be constant per permit. Hence, let the transaction cost function have the form

$$(4.1.10)\ TC_i = t_i |NDP_i|$$

[21] This assumption implies a sort of lexicographic social preferences. It can be justified whenever the decisions on the ceiling level and on the distribution of the corresponding amount of permits are taken by different authorities. For instance, the former may be determined by international agreements prior to the establishment of the permits system.

[22] In Stavins (1995) it makes no difference who pays the transaction cost. However, in our analysis it does affect the results.

As Stavins (1995) shows, the transaction cost creates a zone around the permits price: if a firm's subjective value of an additional permit lies outside that zone the firm exchanges permits in the permits market until its marginal abatement cost equals the gross permits price.[23] On the other hand, if a firm's subjective value of an additional permit lies inside the zone, the firm must operate using only the amount of permits that it was initially endowed with. We are going to refer to these scenarios as Participation Scenario (PS) and Non-Participation Scenario (NPS) according to whether a firm enters the permits market or not. Under the NPS scenario a firm has the choice to adjust its production and/or abatement levels in order to comply with its environmental constraint. On the other hand, a firm under the PS scenario has the same choices and, moreover, it can change the number of permits in its possession. Since a firm evaluates an additional permit depending on how many permits it had initially, we conclude that a government may use strategically the permits distribution to compel domestic firms to choose the PS or the NPS scenario.

4.2 Second stage: firms' choices

To proceed with our analysis let us *ad interim* assume that only the domestic government imposes an environmental constraint on its firms while the foreign government does not. Following the initial distribution of permits, firms decide whether they will participate in the permits market, and if they do, whether they will buy or sell permits. In the next two subsections we derive domestic firms' reaction functions in the PS and NPS scenario, and in the third subsection we derive the foreign firm's reaction function.

4.2.1 Domestic firms' profit maximization problem under NPS scenario

Firms under NPS scenario have to maximize the following profit function

(4.2.1) $\Pi_i = P(q_i, q_j, q_3)q_i - C_i(q_i) - AC_i(q_i, \alpha_i)$,

where $i = 1,2$, $j = 1,2$, and $i \neq j$, subject to the environmental constraint as it is given by equation (4.1.7). Hence, substituting equations (4.1.1), (4.1.5), and (4.1.9) we can state i firm's profit maximization problem in Langrangean form as

$$(4.2.2)\quad \max_{q_i, a_i} L_i = (A - q_i - q_j - q_3)q_i - c_i q_i - \frac{1}{2}\varepsilon_i(\alpha_i q_i)^2 - \lambda_i(e_i - A_i - \bar{e}_i)$$

[23] *I.e.* permits price plus or minus the transaction cost, depending on whether a firm is either a seller or a buyer in the permits market).

Thus, first order conditions are

$$(4.2.3a)\ \frac{\partial L_i}{\partial q_i} = 0 \Rightarrow A - 2q_i - q_{-i} - c_i - \varepsilon_i \alpha_i^2 q_i - \lambda_i \rho_i + \lambda_i \alpha_i = 0,$$

$$(4.2.3b)\ \frac{\partial L_i}{\partial \alpha_i} = 0 \Rightarrow -\varepsilon_i \alpha_i q_i^2 + \lambda_i q_i = 0,$$

$$(4.2.3c)\ \frac{\partial L_i}{\partial \lambda_i} = 0 \Rightarrow \rho_i q_i - \alpha_i q_i - \bar{e}_i = 0.$$

Equation (4.2.3b) yields

$$(4.2.4)\ \varepsilon_i \alpha_i q_i = \lambda_i,$$

which states that the Langrage multiplier, that is the shadow value of emissions, equals the marginal cost of abatement. Substituting (4.2.4) into (4.2.3a) and rearranging we get the reaction function of a firm that operates under NPS scenario, that is

$$(4.2.5)\ q_i = \frac{A - c_i - \rho_i \lambda_i}{2} - \frac{1}{2} q_j - \frac{1}{2} q_3$$

4.2.2Domestic firms' profit maximization problem under PS scenario

Firms within the TEP market have to maximize the following profit function

$$(4.2.6)\ \Pi_i = P(q_i, q_j, q_3) q_i - C_i(q_i) - AC_i(q_i, \alpha_i) - P^E \cdot NDP_i - TC_i,$$

where P^E is the permits price. In this case we must examine whether a firm is a seller or a buyer of permits. The revenue from selling one permit is given by the difference between the permits price and the marginal transaction cost, *i.e.*, $P^E - t_i$, for $i = 1,2$. On the other hand, a buyer has to pay the sum of the permit price and the marginal transaction cost, *i.e.*, $P^E + t_i$, for $i = 1,2$. Taking that into account and substituting equations (4.1.1), (4.1.5), and (4.1.8)-(4.1.10) into (4.2.6) we can state i's firm profit maximization problem as

$$(4.2.7)\ \max \Pi_i = (A - q_i - q_{-i}) q_i - c_i q_i - \frac{1}{2} \varepsilon_i (\alpha_i q_i)^2 - (P^E + t_i)(e_i - A_i - \bar{e}_i),$$

if the firm is a buyer, and

$$(4.2.8)\ \max \Pi_i = (A - q_i - q_{-i}) q_i - c_i q_i - \frac{1}{2} \varepsilon_i (\alpha_i q_i)^2 - (P^E - t_i)(e_i - A_i - \bar{e}_i),$$

if, the firm is a seller, where $q_{-i} = q_j + q_3$, $j = 1,2$ and $j \neq i$. The first order conditions of the above maximization problems are

$$(4.2.7a)\ \frac{\partial \Pi_i}{\partial q_i}=0 \Rightarrow A-2q_i-q_{-i}-c_i-\varepsilon_i\alpha_i^2 q_i-(P^E+t_i)\rho_i+(P^E+t_i)\alpha_i=0,$$

$$(4.2.7b)\ \frac{\partial \Pi_i}{\partial \alpha_i}=0 \Rightarrow -\varepsilon_i\alpha_i q_i^2+(P^E+t_i)q_i=0,$$

and

$$(4.2.8a)\ \frac{\partial \Pi_i}{\partial q_i}=0 \Rightarrow A-2q_i-q_{-i}-c_i-\varepsilon_i\alpha_i^2 q_i-(P^E-t_i)\rho_i+(P^E-t_i)\alpha_i=0,$$

$$(4.2.8b)\ \frac{\partial \Pi_i}{\partial \alpha_i}=0 \Rightarrow -\varepsilon_i\alpha_i q_i^2+(P^E-t_i)q_i=0,$$

correspondingly. Following the same process as in the case of NPS scenario we get the reaction function of a firm that operates under the PS scenario. In the case that firm i is a buyer its reaction function is

$$(4.2.9)\ q_i=\frac{A-c_i-\rho_i(P^E+t_i)}{2}-\frac{1}{2}q_j-\frac{1}{2}q_3,$$

while if it is seller, its reaction function is

$$(4.2.10)\ q_i=\frac{A-c_i-\rho_i(P^E-t_i)}{2}-\frac{1}{2}q_j-\frac{1}{2}q_3.$$

4.2.3 Foreign firm's maximization problem

The foreign firm faces no environmental constraint. Thus, firm 3 has to maximize the following profit function

$$(4.2.11)\ \Pi_3=P(Q,q_3)q_3-C_3(q_3)$$

Substituting equations (4.1.1) and (4.1.9) into equation (4.2.11) we can state a foreign firm's maximization problem as

$$(4.2.12)\ \max\Pi_3=(A-Q-q_3)q_3-c_3q_3$$

The corresponding FOC is

$$(4.2.13)\ \frac{\partial \Pi_3}{\partial q_3}=0 \Rightarrow A-2q_3-\sum_{i=1}^{2}q_i-c_3=0,$$

thus yielding the reaction function

$$(4.2.14)\ q_3=\frac{A-c_3}{2}-\frac{1}{2}Q$$

There are many sub-cases according to whether one or both firms participate in the permits market as a buyer, seller, or not at all. Choosing from (4.2.5), (4.2.9), and (4.2.10) the two expression that are appropriate for each sub-case along with equation (4.2.14) describing the behavior of the foreign firm, we can constitute a system of three reaction functions. Solving this system yields the optimal quantities as functions of cost and demand parameters as well as of the values of the Langrage multipliers λ_k of the $k \in [0,2]$ domestic firms that do not participate in the TEP market. Moreover, the domestic firms' optimal abatement effort is completely defined by solving the first order conditions (4.2.3b), (4.2.7b), and (4.2.8b) for $A_i = a_i q_i$. Thus, optimal abatement efforts are given by

$$(4.2.15)\ A_i^o = (\lambda_i / \varepsilon_i),$$

if the firm chooses the NPS scenario, and

$$(4.2.16)\ A_i^o = [(P^E \pm t)/\varepsilon_i]$$

if the firm chooses the PS scenario.

4.3 First stage: domestic government choice

The sub-game perfect Nash equilibrium of a multi-stage game is found by solving the game backwards. Thus, in the first stage we assume that the domestic government chooses the distribution of permits in order to maximize the social welfare function given the optimal decisions of all firms in the second stage. Under the assumptions of a third market for the final output and of a fixed ceiling on aggregate emissions, the domestic government wants to maximize the joint profits of its firms, with respect to the distribution of permits and subject to the environmental constraint, that is

$$(4.3.1) \max_{\bar{e}} W = \sum_{\substack{i=1 \\ i \neq j}}^{2} \Pi_i [q_i(\bar{e}), q_{-i}(\bar{e})]$$

$$\text{s.t. } \bar{E} = \sum_{i=1}^{2} \bar{e}_i ,$$

where $\bar{e} = [\bar{e}_1, \bar{e}_2]$, and q_i is the optimal quantity of firm $i = 1,2$.[24]

It is clear that the optimal quantities depend upon the firm's decision to participate or not in the permits market, and this decision depends upon the initial

[24] This social welfare function has a lexicographic element in its structure: we assume that the government gives first priority to the environmental protection. Provided that this goal has been achieved, the government choose the distribution of permits that maximizes the joint profit of its firms. While it may be argued that in many instances there is some substitutability between these two goals, emission levels are often imposed exogenously by international environmental agreements such as the Kyoto Protocol.

allocation of permits. Thus, the initial distribution has two effects on the choice of output: *a)* a direct strategic effect reflecting the impact of permits allocation on equilibrium quantities for given participation decisions of the firms, and *b)* an indirect strategic effect reflecting the impact of permits allocation on equilibrium qualities trough affecting each firm's decision on whether to participate in the permits market.

4.4 The firms' choice of the regime

We return to the firm's choice and we first examine each firm's decision to participate or not in the permits market. We know that the objective value of a permit is reflected in the gross permit price, $P^E \pm t_i$, that is, in what a firm has to pay (receive) in order to acquire (sell) an extra permit. On the other hand, what a firm is willing to pay (receive) in order to buy (sell) an additional permit it is given by the Langrangean multiplier of the NPS scenario. Stated formally the condition for i firm's non participation in the permits market is

(4.4.1) $P^E - t_i < \lambda_i < P^E + t_i$

Unfortunately, the use of condition (4.4.1) in its general form lacks tractability. We proceed, therefore, by analyzing some specific examples.

5. THE SYMMETRIC CASE

5.1 Assumptions

Let all firms face the same marginal production cost (*i.e.* $c_i = c$ for all i's) and the same technological parameter on the emission generating process (*i.e.* $\rho_i = \rho$ for all i's) as well as on the abatement process (*i.e.* $e_i = e$ for all i's). Moreover, without loss of generality, let $\rho = e = 1$. Finally, assume that the domestic firms face the same marginal transaction cost in the TEP market (*i.e.* $t_1 = t_2 = t > 0$).

5.2 Finding optimal quantities

Depending on the initial distribution of permits there are 3^2 potential scenarios stemming from all possible combinations of the domestic firms' decisions. It should be noticed that which of these scenarios are going to be possible are determined endogenously. In order to simplify our analysis we are going to examine only five of them: *a)* both firms chooses not to participate in the permits market, *b)* firm 1 is a permits buyer while firm 2 chooses not to participate, *c)* firm 2 is a permits buyer while firm 1 chooses not to participate, *d)* firm 1 is a permits buyer while firm 2 is a permits seller, and *e)* firm 2 is a permits buyer while firm 1 is a permits seller. The necessary and sufficient conditions for the existence of these specific sub-cases will be presented in the next section.[25] Thus, using the assumptions of section 5.1 we can define five different systems of reaction functions, each one corresponding to a specific sub-case, and solve for the optimal quantities.

5.2.1 Sub-case1: Both domestic firms under NPS scenario

Using equation (4.2.5) for both the domestic firms and equation (4.2.14) for the foreign firm, the system of reaction functions is

[25] We are following at this stage a backward analysis: we first examine these specific sub-cases and next in subsections (5.3.1) and (5.3.2) we derive the conditions for the existence of these sub-cases.

$$(5.2.1)\quad \begin{cases} q_1 = \frac{1}{2}(A - c - \lambda_1) - \frac{1}{2}q_2 - \frac{1}{2}q_3 \\ q_2 = \frac{1}{2}(A - c - \lambda_2) - \frac{1}{2}q_1 - \frac{1}{2}q_3 \\ q_3 = \frac{1}{2}(A - c) - \frac{1}{2}q_1 - \frac{1}{2}q_2 \end{cases}.$$

The solution of the above system yields,

$$(5.2.2)\quad \begin{cases} q_1 = \frac{1}{4}(A - c) - \frac{1}{4}(3\lambda_1 - \lambda_2) \\ q_2 = \frac{1}{4}(A - c) - \frac{1}{4}(3\lambda_2 - \lambda_1), \\ q_3 = \frac{1}{4}(A - c) + \frac{1}{4}(\lambda_1 + \lambda_2) \end{cases} \quad \text{or} \quad \begin{cases} q_1 = \hat{q} - \frac{1}{4}(3\lambda_1 - \lambda_2) \\ q_2 = \hat{q} - \frac{1}{4}(3\lambda_2 - \lambda_1), \\ q_3 = \hat{q} + \frac{1}{4}(\lambda_1 + \lambda_2) \end{cases}$$

where $\hat{q} = \hat{q}_1 = \hat{q}_2 = \hat{q}_3$ is the optimal quantity of firms in the absence of environmental regulation. Substituting q_1 and q_2 as given by equations (5.2.2) into (4.2.3c) and using (4.2.4), yields the system

$$(5.2.3)\quad \begin{cases} \frac{1}{4}(A - c - 7\lambda_1 + \lambda_2 - 4\overline{e}_1) = 0 \\ \frac{1}{4}(A - c + \lambda_1 - 7\lambda_2 - \overline{E} + 4\overline{e}_1) = 0 \end{cases},$$

where for the second equation we use the identity $\overline{E} = \overline{e}_1 + \overline{e}_2$. Solving the above system yields the values of λ_1 and λ_2 as functions of the initial distribution (i.e. functions of $\overline{e}_1$), that is

$$(5.2.4)\quad \begin{cases} \lambda_1 = \frac{1}{12}(2A - 2c - \overline{E} - 6\overline{e}_1) = \frac{1}{12}(8\hat{q} - \overline{E} - 6\overline{e}_1) \\ \lambda_2 = \frac{1}{12}(2A - 2c - 7\overline{E} + 6\overline{e}_1) = \frac{1}{12}(8\hat{q} - 7\overline{E} + 6\overline{e}_1) \end{cases}$$

Equations (5.2.4) represent the shadow price of an additional permit for firm 1 and firm 2 given that their domestic competitor chooses the NPS scenario. Substituting (5.2.4) into (5.2.2) yields optimal quantities as functions only of demand and cost parameters as well as of the initial distribution, that is

$$
(5.2.5)\ \begin{cases} q_1 = \dfrac{1}{12}(2A-2c-\overline{E}+6\overline{e}_1) \\ q_2 = \dfrac{1}{12}(2A-2c+5\overline{E}-6\overline{e}_1) \\ q_3 = \dfrac{1}{6}(2A-2c-\overline{E}) \end{cases}, \text{ or } \begin{cases} q_1 = \dfrac{1}{12}(8\hat{q}-\overline{E}+6\overline{e}_1) \\ q_2 = \dfrac{1}{12}(8\hat{q}+5\overline{E}-6\overline{e}_1) \\ q_3 = \dfrac{1}{6}(8\hat{q}-\overline{E}) \end{cases}
$$

There are some interesting features stemming from the above results:

a) adding the first two equalities and rearranging we get $Q=(1/3)[\hat{Q}+(\hat{Q}-E)]$. Thus, as it is expected, domestic production decreases due to environmental regulation of the domestic government.

b) rearranging the third equality yields $q_3 = \hat{q}+(1/6)(\hat{Q}-\overline{E}) > \hat{q}$, with the last inequality to because $\hat{Q}-\overline{E} = \hat{E}-\overline{E} > 0$. Thus, as it is also expected, the foreign firm increases its production.

5.2.2 Sub-case2: Firm 1 buyer of permits – firm 2 under NPS

Using equations (4.2.9) (4.2.5) and (4.2.14) for the firm 1, firm 2, and firm 3, correspondingly, we construct the system of reaction functions for this sub-case, and by solving it we get

$$
(5.2.6)\ \begin{cases} q_1 = \dfrac{1}{4}(A-c)-\dfrac{1}{4}[3(P^E+t)-\lambda_2] \\ q_2 = \dfrac{1}{4}(A-c)-\dfrac{1}{4}[3\lambda_2-(P^E+t)], \\ q_3 = \dfrac{1}{4}(A-c)+\dfrac{1}{4}[(P^E+t)+\lambda_2] \end{cases} \text{ or } \begin{cases} q_1 = \hat{q}-\dfrac{1}{4}[3(P^E+t)-\lambda_2] \\ q_2 = \hat{q}-\dfrac{1}{4}[3\lambda_2-(P^E+t)] \\ q_3 = \hat{q}+\dfrac{1}{4}[(P^E+t)+\lambda_2] \end{cases}
$$

Substituting q_1 form equation (5.2.6) into (4.2.3c) and using (4.2.4), yields the value of λ_2, that is

$$
(5.2.7)\ \lambda_2 = \frac{1}{7}(A-c+P^E+t-4\overline{E}+4\overline{e}_1) = \frac{1}{7}(4\hat{q}+P^E+t-4\overline{E}+4\overline{e}_1)
$$

Equation (5.2.7) represents the shadow price of an additional permit for firm 2 given that firm 1 chooses the PS scenario. Finally, substituting equation (5.2.7) back into equation (5.2.6) we get the optimal quantities for sub-case 2 as functions of cost and demand parameters only as well as of the initial distribution of permits

$$(5.2.8)\ \begin{cases} q_1 = \frac{1}{7}(2A-2c-5P^E-5t-\overline{E}+\overline{e}_1) \\ q_2 = \frac{1}{7}(2A-2c+P^E+t+3\overline{E}-3\overline{e}_1) \\ q_3 = \frac{1}{7}(2A-2c+2P^E+2t-\overline{E}+\overline{e}_1) \end{cases}, \text{ or } \begin{cases} q_1 = \frac{1}{7}(8\hat{q}-5P^E-5t-\overline{E}+\overline{e}_1) \\ q_2 = \frac{1}{7}(8\hat{q}+P^E+t+3\overline{E}-3\overline{e}_1) \\ q_3 = \frac{1}{7}(8\hat{q}+2P^E+2t-\overline{E}+\overline{e}_1) \end{cases}$$

5.2.3 Sub-case3: Firm 2 buyer of permits – firm 1 under NPS

Since sub-case 3 is symmetric to sub-case 2, the Langrange multiplier of firm 1 is given by

$$(5.2.9)\ \lambda_1 = \frac{1}{7}(A-c+P^E+t-4\overline{e}_1) = \frac{1}{7}(4\hat{q}+P^E+t-4\overline{e}_1).$$

Equation (5.2.9) represents the shadow price of an additional permit for firm 1 given that firm 2 chooses the PS scenario. Correspondingly, the optimal quantities are given by

$$(5.2.10)\ \begin{cases} q_1 = \frac{1}{7}(2A-2c+P^E+t+3\overline{E}-3\overline{e}_1) \\ q_2 = \frac{1}{7}(2A-2c-5P^E-5t-\overline{E}+\overline{e}_1) \\ q_3 = \frac{1}{7}(2A-2c+2P^E+2t-\overline{E}+\overline{e}_1) \end{cases}, \text{ or } \begin{cases} q_1 = \frac{1}{7}(8\hat{q}+P^E+t+3\overline{E}-3\overline{e}_1) \\ q_2 = \frac{1}{7}(8\hat{q}-5P^E-5t-\overline{E}+\overline{e}_1) \\ q_3 = \frac{1}{7}(8\hat{q}+2P^E+2t-\overline{E}+\overline{e}_1) \end{cases}$$

5.2.4 Sub-case4: Firm 1 buyer of permits – firm 2 seller of permits

Constructing the proper system of reaction functions for the sub-case 4 and solving it yields

$$(5.2.11)\ \begin{cases} q_1 = \frac{1}{4}(A-c-2P^E-4t) \\ q_2 = \frac{1}{4}(A-c-2P^E+4t) \\ q_3 = \frac{1}{4}(A-c+2P^E) \end{cases}, \text{ or } \begin{cases} q_1 = \hat{q}-\frac{1}{2}P^E-t \\ q_2 = \hat{q}-\frac{1}{2}P^E+t \\ q_3 = \hat{q}+\frac{1}{2}P^E \end{cases}$$

5.2.5 Sub-case5: Firm 1 seller of permits – firm 2 buyer of permits

Since sub-case 5 is symmetric to sub-case 4, the optimal quantities are given by

$$(5.2.12)\ \begin{cases} q_1 = \frac{1}{4}(A - c - 2P^E + 4t) \\ q_2 = \frac{1}{4}(A - c - 2P^E - 4t) \\ q_3 = \frac{1}{4}(A - c + 2P^E) \end{cases}, \text{ or } \begin{cases} q_1 = \hat{q} - \frac{1}{2}P^E + t \\ q_2 = \hat{q} - \frac{1}{2}P^E - t \\ q_3 = \hat{q} + \frac{1}{2}P^E \end{cases}$$

5.3 Initial distribution and scenario choice

We are now able to define the limits of $\bar{e}_1$'s in order to justify the existence of the five sub-cases described above by using inequality (4.4.1) and the values of λ_i as given by the equations (5.2.4), (5.2.7), and (5.2.9) for the sub-cases 1, 2, and 3 correspondingly.

5.3.1 Necessary conditions for sub-case 1

Using inequality (4.4.1) and equations (5.2.4) we get

(5.3.1a) $\Delta < \bar{e}_1 < Z$,

and

(5.3.1b) $H < \bar{e}_1 < \Theta$,

where $\Delta=(1/6)[8\hat{q}-12(P^E+t)-\bar{E}]$, $Z=(1/6)[8\hat{q}-12(P^E-t)-\bar{E}]$, $H=(1/6)[12(P^E-t)+7\bar{E}-8\hat{q}]$, and $\Theta=(1/6)[12(P^E+t)+7\bar{E}-8\hat{q}]$. Inequality (5.3.1a) is the condition for firm 1 to be under NPS scenario given that firm 2 is under NPS scenario, and *vice-versa* for inequality (5.3.1b). Thus, when $\bar{e}_1$ lies within the intersection of these two sets no firm will choose to participate in the TEP market. We know that the firms will alter their regime choices and they are going to entry the TEP market for $\bar{e}_1 \notin [\Delta, Z] \cap [H, \Theta]$. However, we do not know the order in which the firms will enter the TEP market. This order is important since if any of the domestic firms enters the TEP market, the additional permit's subjective value of the firm that stays in the NPS scenario is altered. The intuition for this change is the following: after one domestic firm enters the TEP market, domestically distributed permits are no longer perfect substitutes and the firm that stays under the NPS scenario looses a competitive advantage.

Let us assume that there is a value of $\bar{e}_1$ say $\bar{e}_1^c$, satisfying both (5.3.1a) and (5.3.1b), for which both firms evaluate an extra permit equally, *i.e.*

$\lambda_1(\bar{e}_1^c) = \lambda_2(\bar{e}_1^c) = P^E + \delta$, where $|\delta| < t$.[26] Clearly, since this is a completely symmetric case, the critical value of $\bar{e}_1$ that equalizes λ_i for $i = 1,2$ is $\overline{E}/2$. Getting $(d\lambda_1 / d\bar{e}_1) = -(d\lambda_2 / d\bar{e}_1)$ from equation (5.2.4) and using inequality (4.4.1) we are able to compare the distances that λ_i have to cover from point $(P^E + \delta)$ to the points $(P^E \pm t)$ as $\bar{e}_1$ changes from the critical level $\bar{e}_1^c$. Summarizing the results we get:

***a)* For $\bar{e}_1 > \bar{e}_1^c$:**

- If $t + \delta > t - \delta$, firm 2 enters the TEP market as a seller prior to firm 1 who is going to enter the TEP market as a buyer.
- If $t - \delta < t + \delta$, firm 1 enters the TEP market as a buyer prior to firm 2 who is going to enter the TEP market as a seller.

***b)* For $\bar{e}_1 < \bar{e}_1^c$:**

- If $t + \delta > t - \delta$, firm 1 enters the TEP market as a seller prior to firm 2 who is going to enter the TEP market as a buyer.
- If $t - \delta < t + \delta$, firm 2 enters the TEP market as a buyer prior to firm 1 who is going to enter the TEP market as a seller.

Thus, assuming that $t - \delta > t + \delta \Rightarrow \delta < 0$ we get $[\Delta, \mathrm{Z}] \cap [\mathrm{H}, \Theta] = [\Delta, \Theta]$, that is

$$(5.3.2)\ \frac{1}{6}[8\hat{q} - 12(P^E + t) - \overline{E})] < \bar{e}_1 < \frac{1}{6}[12(P^E + t) + 7\overline{E} - 8\hat{q}]$$

Inequality (5.3.2) represents, under our assumptions, the condition for both domestic firms to choose NPS scenario. For levels of $\bar{e}_1$ less than Δ firm 1 will enter the TEP market as a permits buyer while firm 2 stays under the NPS scenario until its subjective value of an additional permit is less than the $P^E - t$. Respectively, for levels of $\bar{e}_1$ greater than Θ the opposite is true.

Examining condition (5.3.2) we find that necessary and sufficient condition for the existence of sub-case 1 is that $\Delta - \Theta > 0$, that is

$$(5.3.3)\ \hat{Q} - \overline{E} < 3(P^E + t),$$

where $\hat{Q}$ is the domestic production in the absence of environmental regulation. Since we have assumed that $\rho_i = 1$ for all i, using equations (4.1.2) and (4.1.3) we get

[26] Note that the value of δ can be either positive of negative.

$\hat{Q} = \hat{E}$, the unregulated total emissions level. Thus, inequality (5.3.3) can be written as

(5.3.3a) $\hat{E} - \overline{E} < 3(P^{E} + t)$

Stated under this form, this condition means that the weaker the environmental regulation the more likely the existence of sub-case 1.

<u>5.3.2 Necessary conditions for sub-cases 2 and 3</u>

Using inequality (4.4.1) and equations (5.2.7), (5.2.9) we get

(5.3.4a) $\mathrm{I} < \overline{e}_1 < \mathrm{K}$,

and

(5.3.4b) $\Lambda < \overline{e}_1 < \mathrm{M}$,

where $\mathrm{I} = \hat{q} - \frac{6}{4}(P^{E} + t)$, $\mathrm{K} = \hat{q} - \frac{6}{4}P^{E} + 2t$, $\Lambda = \frac{6}{4}P^{E} - 2t + \overline{E} - \hat{q}$, and $\mathrm{M} = \frac{6}{4}(P^{E} + t) + \overline{E} - \hat{q}$. If $\overline{e}_1$ lies within the limits stated by the inequality (5.3.4a) sub-case 3 takes place, while if $\overline{e}_1$ lies within the limits stated by the inequality (5.3.4b) sub-case 2 takes place. Thus, in order to justify our assumptions that *a)* firm 1 enters the TEP market as a buyer prior to firm 2 that chooses the NPS scenario (*i.e.* sub-case 2), and *b)* firm 2 enters the TEP market as a buyer prior to firm 1 that chooses the NPS scenario (*i.e.* sub-case 2), the following condition must be true:

$$\left.\begin{cases} \Lambda - \mathrm{I} > 0 \\ \\ \mathrm{M} - \mathrm{K} > 0 \end{cases}\right\} \Rightarrow \hat{Q} - \overline{E} > 3P^{E}$$

Thus, the necessary and sufficient condition for the existence of sub-cases 2 and 3 is

(5.3.5) $\hat{Q} - \overline{E} > 3P^{E}$

Since we have assumed that $\rho_i = 1$ for all i, using equations (4.1.2) and (4.1.3) we get $\hat{Q} = \hat{E}$. Thus, inequality (5.3.5) can be written as

(5.3.5a) $\hat{E} - \overline{E} > 3P$

Stated in the form of (5.3.5a), this condition means that the stronger the environmental regulation the more likely the existence of sub-cases 2 and 3.

At this point, we are able to combine conditions (5.3.3a) and (5.3.5a).

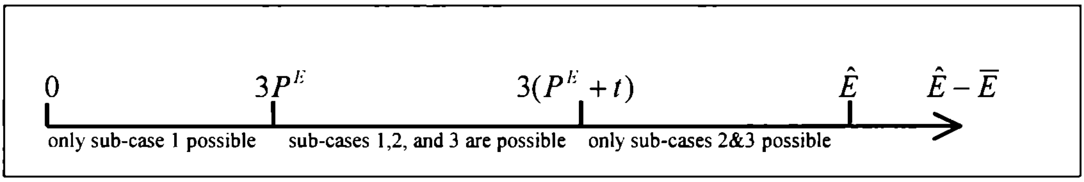


figure 1: environmental regulation and sub-cases 1,2,and 3.

In figure 1 above we present diagrammatically this combination: on the horizontal axis we measure the difference $\hat{E}-\overline{E}$, which is the pollution reduction imposed by the regulation. Starting from point 0, where $\overline{E}=\hat{E}$ and no environmental regulation takes place, and up to the point of $3P^E$, sub-cases 2 and 3 are impossible. Continuing from this point and up to the point of $3(P^E+t)$, sub-cases 2 and 3, along with sub-case 1, correspond to potential equilibria. Finally, from the point $3(P^E+t)$ and up to the point of $\hat{E}$, where $\overline{E}=0$, sub-case 1 ceases to be possible. Thus, we distinct the following cases:

a) Too strict environmental regulation, i.e. $\hat{E}-\overline{E}>3(P^E+t)$

In such a case condition (5.3.3a) does not hold and thus sub-case 1 does not exist. The intuition here is that, when the environmental regulation is too strict, domestically distributed permits remain very close substitutes despite the internationally organized TEP market. Knowing that, a firm might choose the NPS scenario even if its competitor chooses otherwise. Thus, the domestic firms choose different scenarios the one from the other and inequalities (5.3.4a) and (5.3.4b) represent the limitations for the sub-cases 3 and 2, correspondingly.

b) Too loose environmental regulation, i.e. $\hat{E}-\overline{E}<3P^E$

In such a case condition (5.3.5a) does not hold and sub-cases 2 and 3 do not exist. The intuition is that, when the regulation is too loose, entering the TEP market could give a very strong competitive advantage against to the firm that chooses the NPS scenario since domestically distributed permits are no longer close substitutes. This induces both domestic firms to choose the PS scenario immediately after one of them decides to enter in the TEP market.

c) The intermediate case, i.e. $3P^E<\hat{E}-\overline{E}<3(P^E+t)$

Comparing the inequality (5.3.4a) with Θ, and the inequality (5.3.4b) with Δ we find that

$$\begin{cases} \mathrm{I} < \Theta < \mathrm{K} \\ \Lambda < \Delta < \mathrm{M} \end{cases}$$

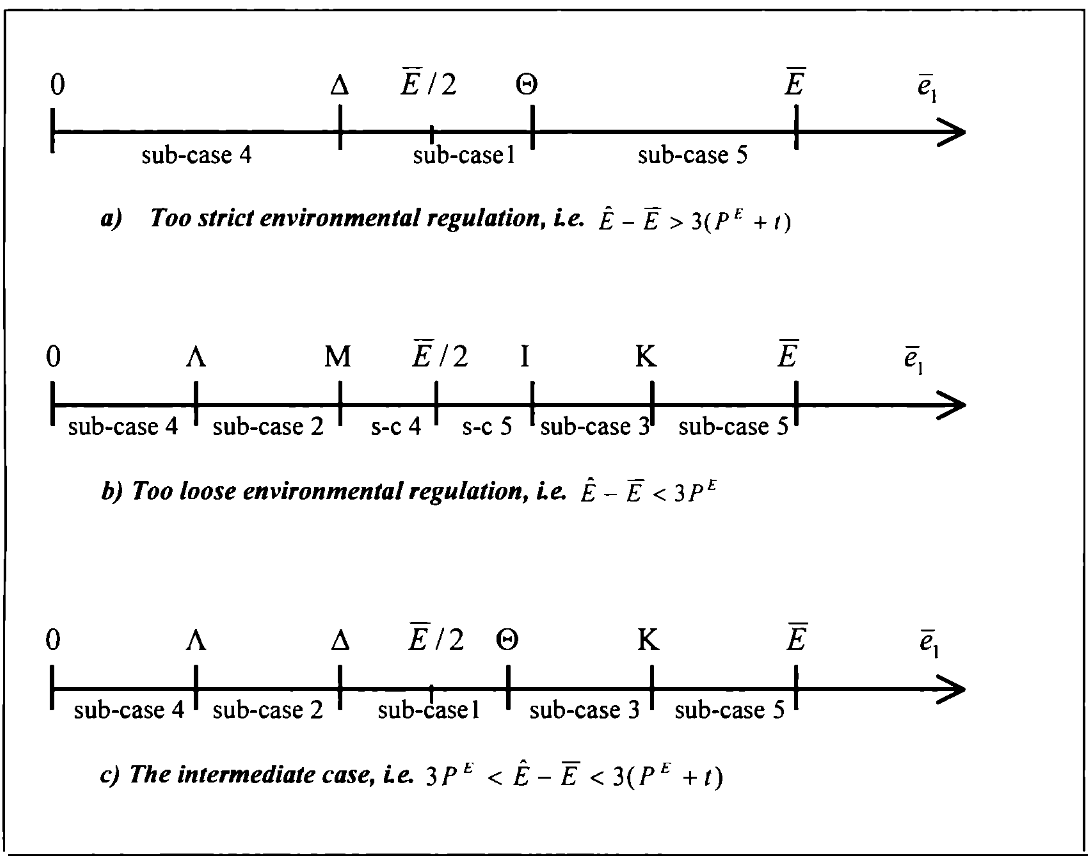
Since condition (5.3.2) is stronger than the conditions (5.3.4a), and (5.3.4b) we get

(5.3.6a) $\Theta < \bar{e}_1 < \mathrm{K}$,

and

(5.3.6b) $\Lambda < \bar{e}_1 < \Delta$.

Inequality (5.3.6a) is the condition for firm 1 to be under the NPS scenario given that firm 2 enters the TEP market, while inequality (5.3.6b) represents the condition for the opposite.



a) Too strict environmental regulation, i.e. $\hat{E} - \bar{E} > 3(P^E + t)$

b) Too loose environmental regulation, i.e. $\hat{E} - \bar{E} < 3P^E$

c) The intermediate case, i.e. $3P^E < \hat{E} - \bar{E} < 3(P^E + t)$

figure 2: initial distribution of permits and domestic firms' scenario choices

For all three cases—the case of strict, loose and intermediate environmental regulation—figure 2 presents the potential scenarios according to the choices of the domestic firms with respect to their participation in the permits market.

5.4 Optimal distribution of permits

As it has been aforementioned, the domestic government decides the distribution of permits by solving the maximization problem (4.3.1). However, we also show that optimal quantities are changing according to the different sub-cases. Thus, the domestic government should find the initial distribution that maximizes domestic firms' joint profits for each sub-case and then to compare these different local maxima in order to find the total maxima.

5.4.1 Initial distribution for each sub-case

We proceed, first, by substituting optimal quantities and optimal abatement efforts for each sub-case into the maximization problem (4.3.1) and solving for the initial distribution.[27]

a) Sub-case 1:

Substituting equations (4.2.15), (5.2.4), and (5.2.5) into the maximization problem (4.3.1) and taking first order condition yields

$$\frac{\partial SP}{\partial \bar{e}_1} = \frac{1}{48}(12\bar{E} - 24\bar{e}_1) = 0$$

Solving this FOC for $\bar{e}_1$ yields

$$(5.4.1)\ \bar{e}_1^o = \frac{1}{2}\bar{E}$$

It is easy to show that equation (5.4.1) represents an acceptable value for $\bar{e}_1$.[28] Moreover, equation (5.4.1) represents the optimal distribution of permits for both the intermediate and the loose environmental regulation case.

b) Sub-case 2:

Substituting equation (4.2.15) for the firm 2 and equation (4.2.16) for the firm 1, along with (5.2.7), and (5.2.8) into the maximization problem (4.3.1) and taking first order condition yields

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[27] For the sub-cases 4 and 5 we assume that domestic firms are exchanging permits only with foreign firms that also participate in the TEP market.

[28] Using inequalities (5.3.2) and conducting the appropriate mathematical operations we find that the condition (5.3.3) ensures the acceptability of $\bar{e}_1^o$.

$$\frac{\partial SP}{\partial \bar{e}_1} = \frac{10}{49}[3(P^E + t) - \hat{Q} + 2\bar{E} - 2\bar{e}_1] = 0$$

Solving this FOC for $\bar{e}_1$ yields

$$(5.4.2a)\ \bar{e}_1^o = \frac{1}{2}[3(P^E + t) - \hat{Q} + 2\bar{E}]$$

However, this is an admissible value for $\bar{e}_1$ only for the case of strict environmental regulation. For the intermediate case, the level of $\bar{e}_1$ that is given by equation (5.4.2.a) lies outside the boundaries of sub-case 2.[29] Thus, in this sub-case we have a corner solution: since $(\partial SP / \partial \bar{e}_1) > 0$[30] the optimal distribution of permits is given by the upper limit of the inequality (5.3.6b), that is

$$(5.4.2b)\ \bar{e}_1^o = \frac{1}{6}[4\hat{Q} - 12(P^E + t) - \bar{E}]$$

c) Sub-case 3:

To solve the government's maximization problem for this sub-case we must substitute equations (4.2.15) for the firm 1, (4.2.16) for the firm 2, along with (5.2.7), and (5.2.8) into the maximization problem (4.3.1) and take first order conditions. Since sub-case 3 is symmetric to the sub-case 2 it is easy to verify that the solutions are

$$(5.4.3a)\ \bar{e}_1^o = \frac{1}{2}[\hat{Q} - 3(P^E + t)],$$

and

$$(5.4.3b)\ \bar{e}_1^o = \frac{1}{6}[12(P^E + t) + 7\bar{E} - 4\hat{Q}]$$

with the former representing the optimal distribution for the strict environmental regulation case, while the latter, which is a corner solution given by the upper limit of the inequality (5.3.6b), concerns the intermediate case.

d) Sub-case 4:

Substituting equation (4.2.16), properly signed, for both the domestic firms along with equations (5.2.11) into the maximization problem (4.3.1) and taking first order conditions yields

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[29] See inequality (5.3.6b).

[30] In order to prove this, we use condition (5.3.3).

$$\frac{\partial SP}{\partial \overline{e}_1} = 2t > 0$$

Thus, a corner solution, given by the upper limit of sub-case 4, applies for each of the loose, strict, and intermediate environmental regulation case. These solutions are

$$(5.4.4a)\ \overline{e}_1^o = \frac{1}{6}[4\hat{Q} - \overline{E} - 12(P^E + t)]$$

$$(5.4.4b)\ \overline{e}_1^o = \frac{1}{2}\overline{E},$$

and

$$(5.4.4c)\ \overline{e}_1^o = \frac{6}{4}P^E - 2t + \overline{E} - \frac{1}{2}\hat{Q},$$

correspondingly.

	Strict Environmental Regulation	Intermediate Environ. Regulation	Loose Environmental Regulation
Sub-case 1	————	$\frac{1}{2}\overline{E}$	$\frac{1}{2}\overline{E}$
Sub-case 2	$\frac{1}{2}[3(P^E + t) - \hat{Q} + 2\overline{E}]$	$\frac{1}{6}[4\hat{Q} - \overline{E} - 12(P^E + t)]$	————
Sub-case 3	$\frac{1}{2}[\hat{Q} - 3(P^E + t)]$	$\frac{1}{6}[12(P^E + t) - 4\hat{Q} + 7\overline{E}]$	————
Sub-case 4	$\frac{1}{2}\overline{E}$	$\frac{1}{4}[6P^E + 8t - 2\hat{Q} + 4\overline{E}]$	$\frac{1}{6}[4\hat{Q} - \overline{E} - 12(P^E + t)]$
Sub-case 5	$\frac{1}{2}\overline{E}$	$\frac{1}{4}[2\hat{Q} - 6P^E - 8t)]$	$\frac{1}{6}[12(P^E + t) - 4\hat{Q} + 7\overline{E}]$

Table 1: Optimal distribution of permits.

e) Sub-case 5:

Since sub-case 5 is symmetric to sub-case 4 it is easy to verify that the optimal distribution of permits for each of the loose, strict, and intermediate environmental regulation case are

(5.4.5a) $\bar{e}_1^o = \frac{1}{2}[12(P^E + t) + 7\bar{E} - 4\hat{Q}]$,

(5.4.5b) $\bar{e}_1^o = \frac{1}{2}\bar{E}$,

and

(5.4.5c) $\bar{e}_1^o = \frac{1}{2}\hat{Q} - \frac{6}{4}P^E + 2t$,

correspondingly. We present a summary of this sub-section's results in table 1 above, where each cell shows the optimal distribution for all sub-cases (rows of the table) and for any extend of the environmental regulation (columns of the table).

5.4.2 Sum of profits for each sub-case

In this sub-section we substitute the optimal distribution, $\bar{e}_1^o$, into the sum of profits finding their maximum levels for each sub-case.

a) Sub-case 1:

Substituting equation (5.4.1) into the sum of profits function we get

(5.4.6) $SP_{sc1}^o = \frac{1}{6}(2\hat{Q}^2 + 2\hat{Q}\cdot\bar{E} - \bar{E}^2)$

Equation (5.4.6) represents the sum of profits for both the intermediate and the loose environmental regulation case.

b) Sub-cases 2 and 3:

Substituting equation (5.4.2a) and (5.4.2b) separately into the sum of profits function we get the maxima for the intermediate and the strict environmental regulation case, that is

(5.4.7a) $SP_{sc2}^o = \frac{1}{18}[4\hat{Q}^2 + 12(P^E + t)(\hat{Q} - \bar{E}) - 10\hat{Q}\cdot\bar{E} - 18(P^E + t)^2 - 5\bar{E}^2]$,

and

(5.4.7b) $SP_{sc2}^o = \frac{1}{2}\left[(P^E + t)[3(P^E + t) - 2(\hat{Q} - \bar{E})] + \hat{Q}^2\right]$,

correspondingly. Moreover, substituting equations (5.4.3a) and (5.4.3b) into the sum of profits function it is easy to verify that

(5.4.8) $SP_{sc2}^o = SP_{sc3}^o$,

for both the intermediate and the strict environmental regulation case.

c) Sub-cases 4 and 5:

Substituting equation (5.4.4a), (5.4.4b), and (5.4.4c) separately into the sum of profits function we get

$$(5.4.9a)\ SP^{o}_{sc4} = \frac{1}{6}[3\hat{Q}^2 - 6P^E(\hat{Q}-\overline{E}) + 8t(\hat{Q}-\overline{E}) + 9(P^E)^2 - 6t^2 - 24P^E t],$$

$$(5.4.9b)\ SP^{o}_{sc4} = \frac{1}{2}\left[\hat{Q}^2 + (P^E+t)[3(P^E+t) - 2(\hat{Q}-\overline{E})] - 2P^E t + 3t^2 + t(\hat{Q}-\overline{E})\right],$$

and

$$(5.4.9c)\ SP^{o}_{sc4} = \frac{1}{8}[4\hat{Q}^2 - 8(P^E+t)(\hat{Q}-\overline{E}) - 12P^E(P^E+t) - 8t^2],$$

for the loose, strict and intermediate environmental regulation case correspondingly. Moreover, substituting equations (5.4.5a), (5.4.5b), and (5.4.5c) into the sum of profits function it is easy to verify that for all kind of environmental regulation

$$(5.4.10)\ SP^{o}_{sc4} = SP^{o}_{sc5}$$

<u>5.4.3 Comparing local maxima</u>

As we have already define the maximum sum of profits for each sub-case and for any environmental regulation in the previous subsection, we are now able to compare them in order to determine the overall maximum.

a) Strict environmental regulation, i.e. $\hat{E} - \overline{E} > 3(P^E + t)$

Comparing equations (5.4.7b) and (5.4.9b) we find that

$$(5.4.11)\ SP^{o}_{sc2} - SP^{o}_{sc4} = \frac{1}{2}[2P^E(\hat{Q}-\overline{E}) - \hat{Q}^2 - 3(P^E)^2 - 9t^2 - 2P^E t] = I.$$

Using condition (5.3.5) we can prove that the sign of equation (5.4.11) depends on the sign and the magnitude of the expression

$$-\hat{Q}^2 + 3(P^E)^2 - 9t^2 - 2P^E t.$$

If this expression is negative then equation (5.4.11) is also negative and the domestic government should prefer sub-case 4 (and 5) instead of sub-case 2 (and 3), while if this expression is positive there is no definite result. However, using the partial derivatives of equation (5.4.11) we find that $(\partial I / \partial P) < 0$, and $(\partial I / \partial t) < 0$. Thus, the

	Strict Environmental Regulation	Intermediate Environmental Regulation	Loose Environmental Regulation
Sub-case 1	———	$\frac{1}{6}(2\hat{Q}^2 + 2\hat{Q}\cdot\overline{E} - \overline{E}^2)$	$\frac{1}{6}(2\hat{Q}^2 + 2\hat{Q}\cdot\overline{E} - \overline{E}^2)$
Sub-case 2	$\frac{1}{2}\left[(P^E+t)[3(P^E+t)-2(\hat{Q}-\overline{E})]+\hat{Q}^2\right]$	$\frac{1}{18}[4\hat{Q}^2+12(P^E+t)(\hat{Q}-\overline{E})-10\hat{Q}\cdot\overline{E}-18(P^E+t)^2-5\overline{E}^2]$	———
Sub-case 3	$\frac{1}{2}\left[(P^E+t)[3(P^E+t)-2(\hat{Q}-\overline{E})]+\hat{Q}^2\right]$	$\frac{1}{18}[4\hat{Q}^2+12(P^E+t)(\hat{Q}-\overline{E})-10\hat{Q}\cdot\overline{E}-18(P^E+t)^2-5\overline{E}^2]$	———
Sub-case 4	$\frac{1}{2}\left[\hat{Q}^2+(P^E+t)[3(P^E+t)-2(\hat{Q}-\overline{E})]-2P^Et+3t^2+t(\hat{Q}-\overline{E})\right]$	$\frac{1}{8}[4\hat{Q}^2-8(P^E+t)(\hat{Q}-\overline{E})-12P^E(P^E+t)-8t^2]$	$\frac{1}{6}[3\hat{Q}^2-6P^E(\hat{Q}-\overline{E})+8t(\hat{Q}-\overline{E})+9(P^E)^2-6t^2-24P^Et]$
Sub-case 5	$\frac{1}{2}\left[\hat{Q}^2+(P^E+t)[3(P^E+t)-2(\hat{Q}-\overline{E})]-2P^Et+3t^2+t(\hat{Q}-\overline{E})\right]$	$\frac{1}{8}[4\hat{Q}^2-8(P^E+t)(\hat{Q}-\overline{E})-12P^E(P^E+t)-8t^2]$	$\frac{1}{6}[3\hat{Q}^2-6P^E(\hat{Q}-\overline{E})+8t(\hat{Q}-\overline{E})+9(P^E)^2-6t^2-24P^Et]$

Table 1: Maximized total domestic profit with respect to the initial distribution.

lower the permits price or the lower the marginal transaction cost, the higher the possibility sub-case 2 (and 3) being better than sub-case 4 (and 5).

b) Loose environmental regulation, i.e. $\hat{E}-\overline{E}<3P^E$

Comparing equations (5.4.6) and (5.4.9a) we find that

$$(5.4.11)\ SP^o_{sc1}-SP^o_{sc4}=\frac{1}{6}\left[-(\hat{Q}-\overline{E})[(\hat{Q}-\overline{E})-6P^E+8t]-9(P^E)^2+6t^2+24P^Et\right].$$

Using partial derivatives we find that $[\partial(\cdot)/\partial P]>0$, and $[\partial(\cdot)/\partial t]<0$. Thus, the higher the permits price or the lower the marginal transaction cost, the higher the possibility the sub-case 1 being better than the sub-cases 4 and 5.***c) The intermediate case, i.e.*** $3P^E<\hat{E}-\overline{E}<3(P^E+t)$

Using equations (5.4.6), and (5.4.7a) we find that

$$SP^o_{sc1}-SP^o_{sc2}=3(P^E+t)-(\hat{Q}-\overline{E}),$$

with the last inequality to hold because of the condition (5.3.3). Thus, the domestic government should always prefer the optimal initial distribution from the set of all initial distributions that induces both domestic firms to choose the NPS scenario.

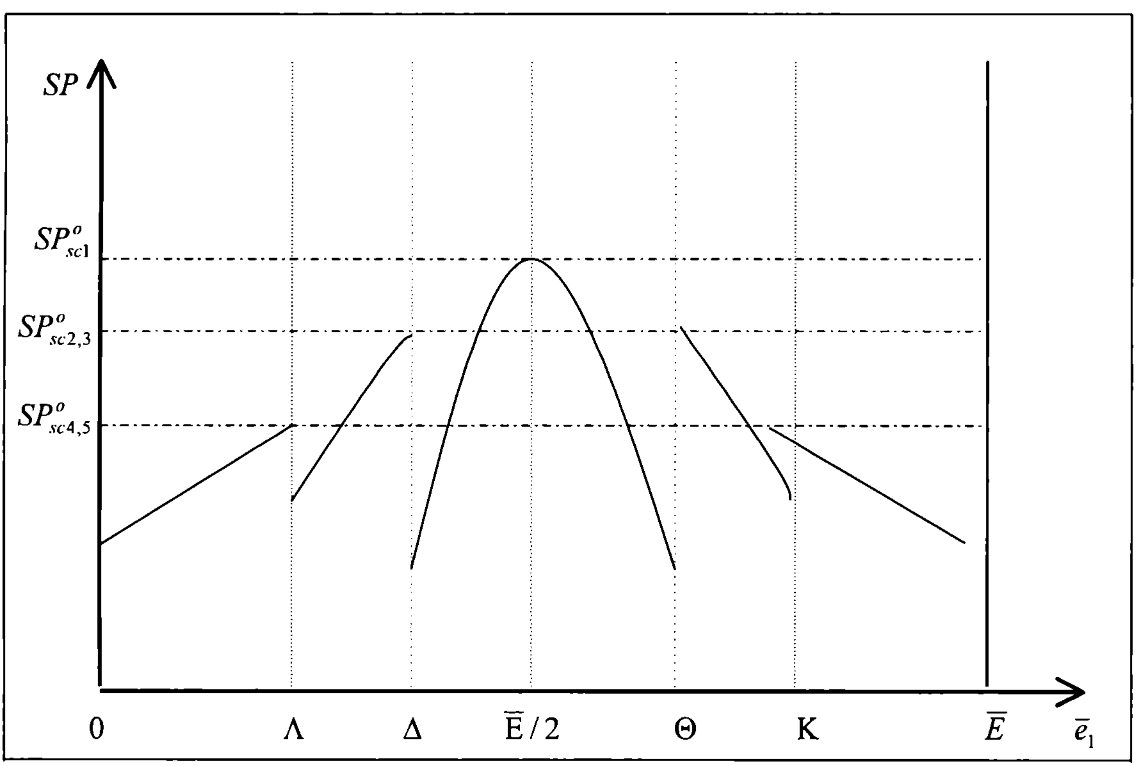

figure3: local and total maximum for the intermediate case

Using equations (5.4.7a) and (5.4.9c) we find that

$$SP^o_{sc4} - SP^o_{sc2} = \frac{5}{18}(3P^E - \hat{Q} + \overline{E})(3P^E - \hat{Q} + 6t + \overline{E}) < 0,$$

with the last inequality to hold because of the conditions (5.3.3) and (5.3.5). Thus, the domestic government should always prefer the optimal initial distribution from the set of all initial distributions that induces both the domestic firms to choose different scenarios from each other, than the optimal initial distribution from the set of all initial distributions that induces both the domestic firms to choose the PS scenario. Immediately follows that, since SP^o_{sc2} is greater than SP^o_{sc4} and SP^o_{sc1} is greater than the SP^o_{sc2}, SP^o_{sc1} represents the total maximum and, consequently, equation (5.4.1) represents the optimal initial distribution for the intermediate environmental regulation case. Figure 3 above shows these results.

In order to complete this analysis we should compare the unbounded sum of profits for each case, that is to compare equations (5.4.6), (5.4.7b), and (5.4.9b). We find that

$$SP^o_{sc1} - SP^o_{sc2} = -\frac{1}{6}[(P^E + t) - (\hat{Q} - \overline{E})]^2 < 0,$$

and

$$SP^o_{sc4} - SP^o_{sc2} = \frac{1}{2}[-(6P^E + 3t) + 2(\hat{Q} - \overline{E})] > 0.$$

The transitivity property results in $SP^o_{sc4} > SP^o_{sc1}$, thus equation (5.4.9b) represents a total maximum. That means that it might be in the best interest of the domestic government to cover the transaction costs in order to induce both the domestic firms to participate in the TEP market, provided that transaction costs are less than the difference $SP^o_{sc4} - SP^o_{sc1}$.

5.5 Conclusions

Despite the simplicity of our model some useful conclusions can be drawn. First, as expected, unilateral emission reductions of the domestic country leads domestic firms in worst position against their international competitors. Compared to the unregulated case, domestic firms' joint production is less and so are their joint profits. On the contrary, foreign firms produce more and increase their joint profits compared to the unregulated case.

Second, for the completely symmetric case the initial distribution that gives equal number of permits to all firms is the optimal one. However, we should be careful with this result: this result depends on crucial assumptions about technological parameters and, moreover, there is always the opportunity for the government to cover completely or in part the transaction costs.

Finally, the most important result of our analysis is that in the presence of transaction costs in the TEP market, governments face two kinds of strategic considerations in the process of distributing tradeable emission permits. First, the initial distribution of permits directly affects the production as long as production or abatement cost differences exist (direct strategic effect). Second, the initial distribution of permits indirectly affects production by inducing firms to choose participation or non-participation in the TEP market (indirect strategic effect). This indirect strategic effect may be a good justification of the following paradox: firms originating from the same country diverge with respect to their decision on whether to participate in the TEP market (as in the case of strict environmental regulation in our model).[31]

In our case, the domestic government has a "tool", the tradeable emission permits system, in order to "fix" a specific problem, the pollution of the environment. However, the implementation of the environmental regulation[32] could cause other inefficiencies like *a)* production cost inefficiency, *b)* abatement cost inefficiency, and *c)* transaction cost inefficiency. The trade-off among these inefficiencies is the one source of the indirect strategic effect. The second source of the indirect strategic effect is the changes in production levels caused by different initial distributions. Thus, we should be careful with the results of this model since domestic firms are assumed to be completely symmetric and there is no production or abatement cost inefficiencies issues. By changing this assumption the trade-offs may be very complicated. The same is true if, for example, we increase the number of the firms, we assume more goods or countries, or we assume other kinds of market distortions.

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[31] Recall transaction costs have been assumed linear to the volume of permits, hence the aforementioned result does not depend on economies of scale in permits transactions.

[32] In our case the initial distribution of permits.

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