R&D COOPERATION, INNOVATION SPILLOVERS AND FIRM LOCATION IN A MODEL OF ENVIRONMENTAL POLICY

by

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Abstract

In this paper, the reaction of firms to the introduction of environmental charges in a given industry is analysed. Firms may decide either to relocate their plants abroad or to adopt a new environmental-friendly technology. The latter can be either developed by investing in R&D or obtained by buying a licence. We show that, even if domestic firms share the same initial technology, at the equilibrium they make different choices in response to the same environmental policy. Some firms decide to cooperate in carrying out environmental R&D, other firms re-locate their plants abroad, and a third group decides to innovate through imitation. The size of the three groups can be affected by the government's industrial, trade and environmental policies.

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1. Introduction

One of the arguments raised against environmental taxation concerns its effects on the competitiveness of firms located in those countries which decide to introduce an emission tax. For example, it is often argued that a tax on CO2 emissions would induce energy intensive firms to relocate their plants in countries adopting a less stringent environmental policy.

The economic literature has recently faced this issue[1] by focusing on the trade-off between fixed and variable (transport) costs of relocation, and the burden of the environmental tax. The results seem to show that relocation may occur, but that this may be a desirable option from a social welfare point of view in the case of local pollution, if the environmental benefit is larger than the economic loss caused by the move of domestic production activities in a foreign country. In this latter case, the tax is an incentive to relocate abroad polluting plants (the so-called NIMBY strategy).

By contrast, in the case of global pollutants, the domestic environmental damage is not reduced by the relocation of firms. It is therefore preferable to prevent polluting (e.g. energy intensive) firms from relocating their plants. This explains why several proposals on the introduction of a carbon tax (e.g. the one proposed in 1992 by the CEC) contain tax exemptions for energy intensive industries.

This paper attempts to provide a further look to this problem by emphasising the role of innovation and R&D cooperation in the decision process that may lead firms to relocate their plants as a reaction to the introduction of an emission tax. The well known argument[2] is that a tax can stimulate R&D and innovation thus leading firms to become more efficient. This increased competitiveness may offset the negative effects on firm's costs produced by the tax. Moreover, firms developing environmental-friendly technologies may have the possibility to sell the new production processes (or the licences) thus making profits in this new market.

There are therefore two economic forces that guide a firm’s decision process. On the one hand, environmental policy increases costs, thus providing an incentive to re-locate plants abroad. On the

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[1] Among the works recently devoted to the issue of firm re-location are Markusen, Morey and Olewiler (1993, 1995), Rauscher (1995), Hoel (1994), Motta and Thisse (1994), Venables (1996).

[2] See Porter (1991).

other hand, by inducing more R&D and innovation, it reduces costs, thus preventing firms from re-locating their plants in countries with less stringent environmental policies. As we will show, these two forces are a function of the number of firms in the country. As the number of firms which innovate increases, the positive external effects of R&D also increases, thus making innovation more profitable. At the same, domestic production and pollution expand, thus increasing the environmental costs paid by firms and making re-location more profitable. This paper analyses the interaction of these two forces and their role in determining the optimal response of firms to environmental policy.

The questions to be answered are the following: what is a firm's reaction to environmental taxation? Will a firm decide to relocate its plants abroad? Or will it choose to innovate? If so, is the R&D strategy going to be decided jointly with the other firms in the industry (R&D cooperation)?

In order to provide an analytical framework to answer the above questions, this paper considers a domestic industry in which an emission tax is introduced and in which the tax is such to induce firms to move their plants to another country -- where no tax is levied -- unless firms decide to change their production technology. However, the new environment-friendly technology is not yet available. Therefore, when firms do not relocate, either they develop the new technology or they imitate the technology developed by other firms. The development of new technologies is assumed to be the outcome of some cooperative R&D efforts among firms (the number of cooperating firms will be endogenously determined). Imitation takes place when some firms prefer to buy the licence to use the new technology from the firms which have decided to carry out R&D. Obviously, no imitation can take place without R&D.

The goal of the paper is twofold:

(i) to determine whether some firms decide to carry out R&D and to innovate, others stay in the country and buy the licence to use the new technology, whereas a third group of firms move to the foreign country;

(ii) to single out the crucial parameters which explain the choice of each firm, and to propose some policy strategies that can provide incentives for polluting firms not to exit the country when this is a desirable option.

The structure of the paper is as follows. The next section presents the model, clarifies its main assumptions and sets the rules of the game. It also determines the optimal production choices of the three groups of firms. Section 3 focuses on imitating firms and determines the demand for licenses to use the environment-friendly technology and its price. Section 4 analyses the formation of the

R&D coalition and discusses under which conditions three groups of firms are going to emerge. The last section will be devoted to analyse the policy implications of the model.

2. Innovation Strategies and Re-location: the Analytical Model.

Consider a *n* firm, perfectly competitive domestic industry. The production process used by these firms is polluting. This induces the government to introduce a tax to control emissions. Pollution is a local as well as a global problem. Emissions depend on the production level chosen by each firm. The emission rate is affected by the innovation activity carried out by the firms which in turn also depends on the incentive policies introduced by the government.

Let $k(q_h)$ be the cost function which represents firm h's technology, $k'>0$, $k''\geq 0$, and $E_h(q_h) = e(.)q_h$ be its linear emission function, where q_h, h=1,2, ... n, is the production level and e(.) is the emission rate to be specified below.

Firms may decide to locate their plants either at home or abroad, where it is assumed that the foreign government does not levy emission charges (alternatively, taxes are lower in the foreign country). Following Xepapadeas (1997, Ch. 2), it can be shown that a government which maximises consumers' utility sets the optimal tax rate equal to the social marginal damage from emissions, where this marginal damage is a growing function of total domestic emissions. Therefore, let t(E) be the emission tax rate, where E are total emissions in the domestic country. Moreover, let $E_h = E_h(q_h) = e(.)q_h$, h = 1,2, ...n, be firm h's emissions.

Assume the tax level to be high enough to induce firms to move their plants abroad unless a new technology, characterised by a sufficiently lower emission-output ratio, is adopted.[3] Firms have therefore two main options: either they re-locate their plants or they innovate. In this latter case they can choose whether to join the group of firms which cooperate on R&D, or they can decide to imitate the cooperating firms. In the latter case, imitating firms buy licences from the cooperating ones – we assume that property rights on the environmental innovation can be established. The price of the licence is denoted by p_x and is set by the R&D cooperating firms.

There may therefore be three groups of firms. Let n_c denote the number of cooperating firms, n_i the number of those which imitate, and n_d the number of firms which re-locate their plants abroad,

3 An interesting extension of this paper would be the endogenisation of the tax rate. This would require to model and solve the game between the governments of the two countries.

$n_c+n_i+n_d = n$ and $0 \leq n_h \leq n$, h=c,i,d. Moreover, let us denote by C, I and D the three groups of firms respectively, where C   I   D = N and $N = \{1,2, ... ,n\}$. The profit functions are as follows.

(1a) $\Pi_c = [pq_c - k(q_c) - t(E)e(.)q_c] + (p_x n_i - F_c)/n_c$ c   C

for R&D cooperation firms, where p is the market price, $p_x n_i$ is the total revenue from the licencing activity, and F_c is the fixed cost of R&D. The R&D profit $(p_x n_i - F_c)$ is shared equally among the n_c firms in the R&D coalition;

(1b) $\Pi_i = [pq_i - k(q_i) - t(E)e(.)q_i] - p_x$ i   I

for the imitating firms (zero innovation spillovers are assumed), and

(1c) $\Pi_d = [pq_d - k(q_d) - t_d q_d] - F_d$ d   D

for the re-locating firms, where t_d are unit transport costs, F_d is the fixed cost of re-location, and t(E) = 0 in the foreign country.

The emission rate e(.) is a function of the technology which is used by firms. Firms in the domestic country share the same technology, either because they develop it or because they buy it. Hence, they are characterised by the same emission rate, which implies the same cost structure k(.)+t(E)e(.)q and, as a consequence, the same production level $q \equiv q_i = q_c$. R&D activities modify the available technology because they focus on the development of environment-friendly production processes. We assume that R&D increasingly reduces the negative impact on the environment of production activities as the number of R&D cooperating firms increases. Therefore, the emission rate is $e(.) = e(n_c)$, $e' \leq 0$.

The consequence of the above remarks is that E -- total emissions in the domestic country – can be defined as:

(2) $E = n_c e(.)q_c + n_i e(.)q_i = (n_c+n_i)e(.)q.$

The government has two policy instruments: an incentive policy to foster the development of environmental-friendly technologies, and a tax policy to internalise damages from polluting emissions. The tax policy leads the government to introduce a tax rate equal to t(E). The tax is obviously paid only by firms which remain in the country. The incentive policy may be directed either to reduce F_c -- the fixed cost of R&D – or to reduce $e(n_c)$ – the emission rate – by providing firms with some free basic research, thus increasing the effectiveness of R&D cooperation among the n_c firms in the R&D coalition.

An important assumption on the (exogenously given) tax rate has to be introduced. We already assumed that the tax rate is high enough to induce all domestic firms to re-locate their plants in the foreign country if no environmental innovation is developed and adopted. We also assume that it is such to induce at least one domestic firm to move its plants abroad even if all domestic firms adopt the innovation and remain in the country.

The first part of the assumption on the tax rate makes it clearer the role of innovation in preventing firms from relocating. Indeed, without innovation, all firms would re-locate. With innovation, they may not do it. The second part emphasises the role of negative environmental externalities. If all firms remain in the country, pollution is high enough to imply a tax rate whose level is such to induce at least one firm to move its plants abroad.

Let us assume the following functional forms: $k(q)=1/2q^2$, $t(E) = tE$, and $e(n_c) = n_c^{-\varepsilon}$, $\varepsilon>0$, where $\varepsilon = -e'(n_c)n_c/e(n_c)$ is the elasticity of the emission rate to the number of R&D cooperating firms. Then domestic firms' profit maximisation leads to:

(3) $$V(b) = \max_{q_c} \Pi_c = \max_{q_i} \Pi_i=1/2(p - b)^2 \qquad c \quad C, \quad i \quad I$$

where $b = t(E)e(n_c)$ is the cost per unit of production of emissions, $\partial V/\partial b<0$, and the optimal production level is $q^*(b) = p-b$. An explicit solution can be obtained by solving the system:

(4a) $$b = tEe(n_c)$$

(4b) $$E = (n_c + n_i)\, e(n_c)\, q^*(b)$$

The emission tax-rate is:

(5a) $$b^*(n_c,n_i) = [p(n_c+n_i)te(n_c)^2]/[1+(n_c+n_i)te(n_c)^2]$$

whereas total domestic emissions are:

(5b) $$E^*(n_c,n_i) = [p(n_c+n_i)e(n_c)]/[1+(n_c+n_i)te(n_c)^2]$$

from which:

(5c) $$q^*(n_c,n_i) = p/[1+(n_c+n_i)te(n_c)^2]$$

(5d) $V^*(n_c,n_i)=1/2p^2/[1+(n_c+n_i)te(n_c)^2]^2$

What is the relationship between the unit environmental tax burden $b^*(n_c,n_i)$ and the number of imitating and cooperating firms? Taking first derivatives, we obtain:

$\partial b^*/\partial n_i > 0$ and

$\partial b^*/\partial n_c \quad te(n_c)^2[1 - 2\varepsilon/\theta]$ for $n_c \geq 1$,

where $\theta = n_c/(n_c+n_i)$. This latter derivative is therefore non-negative when $\theta \geq 2\varepsilon$. Notice that θ belongs to the unit interval. Hence, $\partial b^*/\partial n_c$ is always negative if $\varepsilon >$ _. This implies that an increase in the number of R&D cooperating firms always decreases the unit costs of emissions (this is what we called the strongly convex case). If instead $\varepsilon <$ _, $\partial b^*/\partial n_c$ may be first negative, when θ is very small because a few firms cooperate on R&D, and then positive, as the number of firms in the R&D coalition increases. In this latter (weakly convex) case, an increase of n_c reduces the unit costs of emissions because it increases the environmental efficiency of the new technology. At the same time, a larger number of firms in the domestic country increases the tax burden and therefore the cost of emissions. When n_c is small, the first effect prevails, but when n_c increases, given the decreasing returns of R&D cooperation, the second effect prevails and the unit costs of emissions increase with the number of R&D cooperating firms. [4]

Notice that the dynamics of b* determines the level of profits for domestic firms. Indeed, we can write the value of profits at the optimal production level as:

(6a) $\pi_c(n_c,n_i) = V(b^*(n_c,n_i)) + (p_x n_i - F_c)/n_c \qquad c \quad C$

(6b) $\pi_i(n_c,n_i) = V(b^*(n_c,n_i)) - p_x \qquad i \quad I$

Therefore, given p_x and n_i, an increase of b* reduces domestic firms' profits. This implies that, in the weakly convex case, an increase of the number of firms which join the R&D coalition and remains in the country may be counterproductive, i.e. the effect on profits may be negative.

Let us finally consider the value of profits for re-locating firms. We have:

(7) $V_d(t_d) = \max_{q_d} \Pi_d = 1/2(p-t_d)^2 \qquad d \quad D$

[4] Formally, when $n_c= 0$ the derivative is negative, whereas when $n_c = n$ the derivative is positive if $\varepsilon <$ _. Therefore, there exists a value n° such that $\partial b^*/\partial n_c = 0$.

from which

(8) $$\pi_d = V_d(t_d) - F_d \qquad d \quad D$$

Notice that this value of profits does not depend on n_c and n_i, and therefore it does not depend on $n_d = n - n_c - n_i$. As a consequence, in the sequel, when the analysis will focus on the determination of n_c and n_i, i.e. of the size of the three groups of firms, π_d will be considered as given.

Let us conclude this section by specifying the rules of the game underlying the decision process in the industry. In the first stage, firms choose the group, i.e. one of the three strategies – R&D cooperation, purchase of the licence, re-location – which identifies the group. In the second stage, the optimal production level is determined. The first stage is divided into two sub-stages: in the first one, the R&D coalition is formed which sets the price of the licence taking into account the implications of this choice on the number of imitating firms (and consequently on the number of firms which relocate). In the second sub-stage, given the price of the licence and the number of firms in the R&D coalition, the number of imitating firms and the number of firms which relocate their plants are determined. This sequence is motivated by the following remark. Entry in the R&D coalition cannot be open, because open membership may reduce profits of firms in the coalition. Hence, the first decision to be taken is the optimal size of the group of firms which cooperatively carry out R&D. The remaining firms will then decide whether or not to stay in the country (by buying the license) or to re-locate.

3. Imitation

The second stage of the game – the production stage – was already solved in the previous section (see eqs. (5)). We can thus move to the first stage. Going backward, let us first determine the size of the group of firms which decide to imitate. These firms, given the available technologies, choose between re-locating their plants abroad and to buy the less polluting technology developed by the R&D cooperating firms. In this latter case their profit is π_i. Otherwise, they obtain π_d. At the equilibrium, no firm in the group I finds it profitable to join the group D, i.e. to re-locate, and no firm in the group D prefers to be in I. Therefore, the equilibrium condition is $\pi_i(n_c,n_i) = \pi_d$, or

(9) $$1/2 \;\; p^{2}/[1+(n_c+n_i)te(n_c)^2]^2 = p_x + \pi_d$$

from which we can solve with respect to n_i. This yields:

(10) $$n_i\,(p_x,n_c,\varepsilon,t,\pi_d) = (1/t)(n_c)^{2\varepsilon}[2^{-}{-}p(p_x+\pi_d)^{-}{-} - 1] - n_c$$

which describes the demand for licences (each firm is assumed to buy one licence only) as a function of their price p_x, of the “quality” of the environmental innovation, here captured by the number of firms in the R&D coalition and by the elasticity parameter ε, and of the strength of the environmental policy (the tax rate t). Notice that $\partial n_i/\partial t < 0$, $\partial n_i/\partial p_x < 0$, $\partial n_i/\partial \pi_d < 0$.

Notice also that the demand for licences must satisfy $0 \leq n_i \leq n - n_c$, which implies:

(11a) $\quad p_x \leq p_M(n_c) = (p^2/2)[1 + tn_c^{(1-2\varepsilon)}]^{-2} - \pi_d$

where $p_M(n_c)$ is the maximum licence price above which the demand for licences is no longer positive, and:

(11b) $\quad p_x > p_m(n_c) = (p^2/2)[1 + tn_c^{-2\varepsilon}n]^{-2} - \pi_d$

where $p_m(n_c)$ is the minimum licence price at which no firm wants to re-locate its plants abroad. Notice that the assumption on the tax rate implies that (11b) must hold as a strict inequality. The two prices $p_M(n_c)$ and $p_m(n_c)$ are non-negative only if:

(12) $\quad \pi_d \leq (p^2/2)[1 + tn_c^{(1-2\varepsilon)}]^{-2}$

Hence, profits abroad cannot be too large, otherwise all firms would like to re-locate.

If (11a) also holds as a strict inequality, the demand for licenses is strictly positive. This implies that the set I is not empty whenever C is non empty. The number of firms in the R&D coalition – the size of C – will be determined in the next section.

The optimal price for the licence to use the less polluting technology developed by the R&D cooperating firms can be computed by maximising the profit function of the firms belonging to C with respect to p_x, given the demand function defined by eq. (10). The profit function is:

(13) $\quad \pi_c = p_x + \pi_d + \{(1/t)(n_c)^{2\varepsilon}[2^{-–}p(p_x+\pi_d)^{-–} - 1] - n_c\}p_x/n_c - F_c/n_c$

whose differentiation with respect to p_x yields:

(14a) $\quad (p_x/A)(\partial A/\partial p_x) = -1$

where $A = (1/t)[2^{-–}p(p_x+\pi_d)^{-–} - 1]$. This first-order condition can be written as a third-order equation by defining $y \equiv (p_x + \pi_d)^{-1/2}$. Then (14a) becomes:

(14b) $y + \pi_d y^3 = 2\sqrt{2}/p$

whose solution uniquely determines y* and therefore p^*_x. First, $\partial^2\pi_c/\partial p_x^2 < 0$ for all $p_x \geq 0$ can easily be computed. Second, the left-hand side of (14b) is an increasing function of y which equals zero when y=0, whereas the right-hand side is constant and strictly positive (see Figure 1 where the function $y + \pi_d y^3$ and the equilibrium value y* are shown). Notice that the optimal price for the licence is independent of n_c -- the number of R&D cooperating firms.[5]

From Figure 1, the effect of a change of p and π_d on the price of licences can be assessed. An increase of p lowers the line $2\sqrt{2}/p$ and therefore y*. As a consequence p^*_x -- the price of licences -- is also lowered. An increase of π_d rotates the function $y + \pi_d y^3$ to the left, thus reducing y* and p^*_x. The equilibrium price of licences is thus defined by the following function

$$p^*_x = p^*_x(\pi_d, p)$$

where $\partial p_x/\partial\pi_d < 0$, $\partial p_x/\partial p < 0$. These results are quite intuitive. A reduction of market price or an increase of profits in the foreign market reduce the relative profitability of the domestic market. Hence, R&D cooperating firms need to set a lower price for their licence if they want to induce the other domestic firms to buy the new technology rather than moving into the foreign country.

Finally, let us verify if the equilibrium price p^*_x satisfies the constraint (11a) and (11b). These can be re-written as:

(15a) $y \geq \sqrt{2}[1 + tn_c^{(1-2\varepsilon)}]/p \equiv y_m$

(15b) $y \leq \sqrt{2}[1 + tn_c^{-2\varepsilon}n]/p \equiv y_M$

Notice that $\sqrt{2}[1 + tn_c^{(1-2\varepsilon)}]/p \leq \sqrt{2}[1 + tn_c^{-2\varepsilon}n]/p$ because $n_c \leq n$. There exist therefore values of p and π_d such that y* belongs to the interval defined by eqs. (15a) and (15b).

4. R&D cooperation

[5] This result is always true for any constant elasticity taxation function.

Before analysing the firms' decision to cooperate on R&D, thus endogenising the number of firms in the R&D coalition, let us summarise the results so far obtained on the structure of the industry. As said above, firms in the industry may be divided into three groups, C, I, D. The partitions of the set N including all firms are as follows:

{ (C),(I),(D),(C,D),(C,I),(I,D),(C,I,D)_

Notice, however, that (I) and (I,D) are not feasible. Indeed, no imitation can occur if C is empty, i.e. if no innovation is developed; (C) and (C,I) are also not feasible because of the assumption on the tax rate; finally, (C,D) is excluded by the assumption on the price of the licences. We are therefore left with two possibilities. Either C is empty and all firms prefer to re-locate their plants abroad. Or C is not empty and three groups of firms (C,I,D) forms at the equilibrium. Let us analyse the size of C. Then, the size of I -- the imitating firms -- will be determined by eq. (10) given the licence price defined by (14b). The remaining $n-n_c-n_i$ firms decide to move their plants abroad.

The number of firms which decide to join the R&D coalition can be determined as follows. After replacing the demand for licenses and their optimal price, the profit function for the cooperating firms becomes:

(16) $$\pi°(n_c) = y^* + (1/n_c)[n_c^{2\varepsilon} A^* p^*_x - F_c]$$

where A* can also be written as $A^* = (1/t)\ [py^*/\sqrt{2} - 1]$ and y* was previously shown to be independent of n_c.

In the case of R&D cooperation, it cannot reasonably be assumed that entry in the coalition is open to all firms. A concept of exclusive membership should rather be used. Indeed there is no reason to assume that R&D cooperating firms let other firms join the coalition if this is going to reduce their profits. As a consequence, the number of firms which cooperate to develop the environment-friendly technology is determined by maximising $\pi°(n_c)$ with respect to n_c. The first order condition is:

(17a) $$(1/n_c^2)[F_c - p^*_x A^*(1-2\varepsilon)nc^{2\varepsilon}] = 0$$

from which

(17b) $$n^*_c = \{F_c/[p^*_x A^*(1-2\varepsilon)]\}^{1/2\varepsilon}$$

Moreover, $d^2\pi°(n_c)/dn_c^2 < 0$ if $1-2\varepsilon > 0$ (the weakly convex case). Notice that this condition is also necessary for $n^*_c < n$. Were $1-2\varepsilon < 0$, $d\pi°(n_c)/dn_c$ would be positive for all positive n_c. In this (strongly convex) case all firms would find it optimal to join the R&D coalition without excluding any potential member. The reason is the strong impact on cost reduction of additional R&D cooperators whenever $\varepsilon > 1/2$.

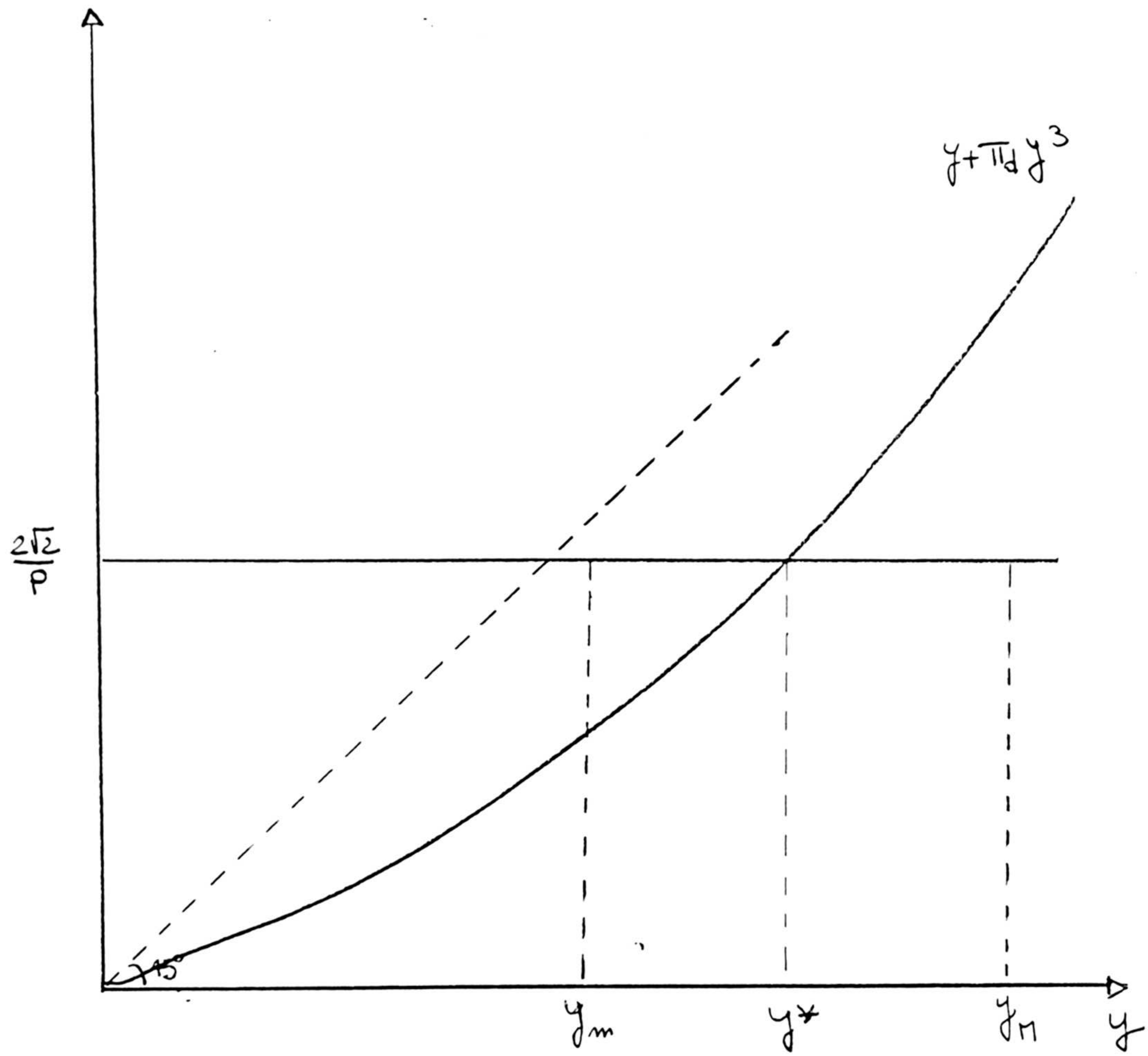
Notice that the optimal number of R&D cooperators defined by (17b) is an increasing function of the fixed cost F_c, whereas it decreases with the price of licenses p^*_x. Again the intuition is quite simple, even if not obvious. An increase of F_c makes it optimal a larger number of cooperators in order to share a larger fixed cost. An increase of p^*_x increases the benefits from the market for licences and therefore reduces the optimal number of cooperators because they can make profits even with a small reduction of costs (i.e. a small size n_c). Were n_c larger, profits would have to be shared between a larger number of cooperators, whereas receiving an increasingly small benefit from their cooperation. An increase of A*, i.e. of π_d, also reduces the number of R&D cooperating firms because it increases the incentive for all firms to relocate their plants in the foreign country. Notice that π_d can be increased by lower trade barriers, lower transport costs, labour costs, etc.

Finally, the determination of the optimal coalition size n^*_c and price of licences p^*_x imply the determination of $n^*_i(n^*_c,p^*_x,\varepsilon,\pi_d,t)$ – the number of firms which prefer to imitate. As a residual, we obtain the number of firms which decide to relocate their plants abroad, i.e. $n^*_d = n - n^*_c - n^*_i$.

5. Conclusions

The implications of the previous analysis can be summarised as follows. In a competitive industry with identical firms, the introduction of environmental taxation induces different replies. Some firms decide to develop a new, environment-friendly technology, which helps them reducing the tax burden; other firms prefer (or are forced) to buy the new technology rather than developing it; whereas a third group of firms decide to relocate their plants in the foreign country. This result is obvioulsy conditional on the assumptions discussed in the previous sections. In particular, the restrictions on the tax rate, on the effects of R&D on the emission rate (the weakly convex case), and on the level of profits in the foreign country are crucial to obtain the above conclusion. If, for example, profits in the foreign country are excessively high – inequality (12) is not satisfied -- all firms would move their plants above. If, by contrast, $\varepsilon > 1/2$, then all firms would find it optimal to join the R&D coalition and to accept the cooperation of all firms. Hence, no re-location would occur.

Fig. 1

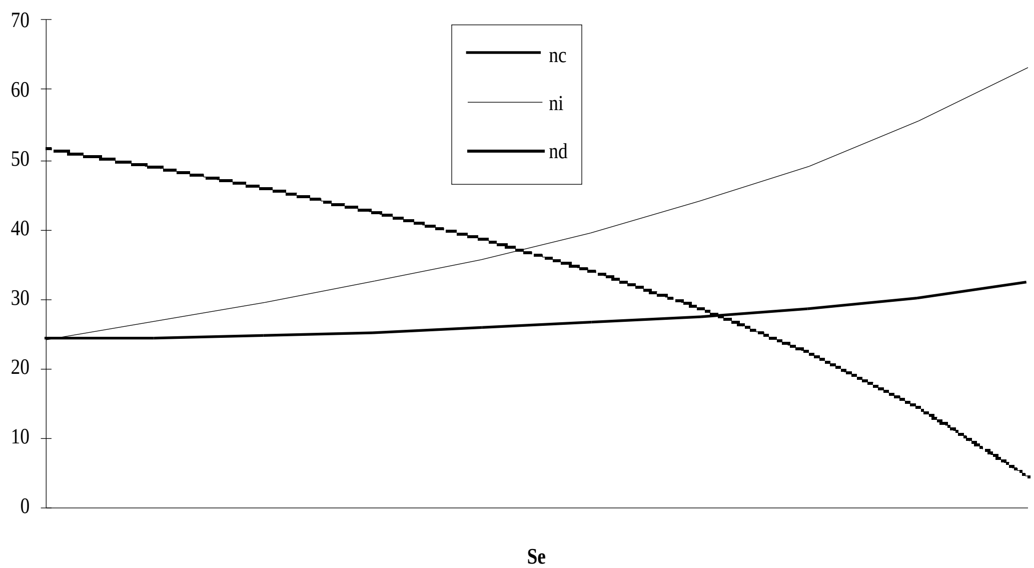


The size of the three groups of firms depends on the parameters of the model. We have seen how an increase of the fixed cost of R&D, an increase of transport costs or of trade barriers -- which reduces profits in the foreign country -- a decrease of the price of licence, all increase the number of firms in the R&D coalition. The same result can be achieved by a governmental policy designed to increase the effectiveness of firms' R&D, for example by stimulating R&D efforts, cooperation and spillovers within coalition members.[6]

Notice that the two industrial policy instruments mentioned in Section 2, i.e. a subsidy on R&D fixed costs and an incentive policy to increase R&D effectiveness, have opposite effects. Only this second policy instrument, e.g. a larger amount of free basic research available to firms, can increase the number of firms in the R&D coalition, thus reducing the number of firms which decide to re-locate their plants abroad.

These results are confirmed by the numerical simulations performed in Boetti *et al.* (1997) using a more complex numerical model based on the theoretical model developed in this paper. The impact of an incentive policy which increases the effectiveness of R&D cooperation on the emission rate is shown in Figure 2, which is drawn from Boetti *et al.* (1997).

Figure 2: *Optimal firm distribution as the R&D effectiveness "s_e" increases*

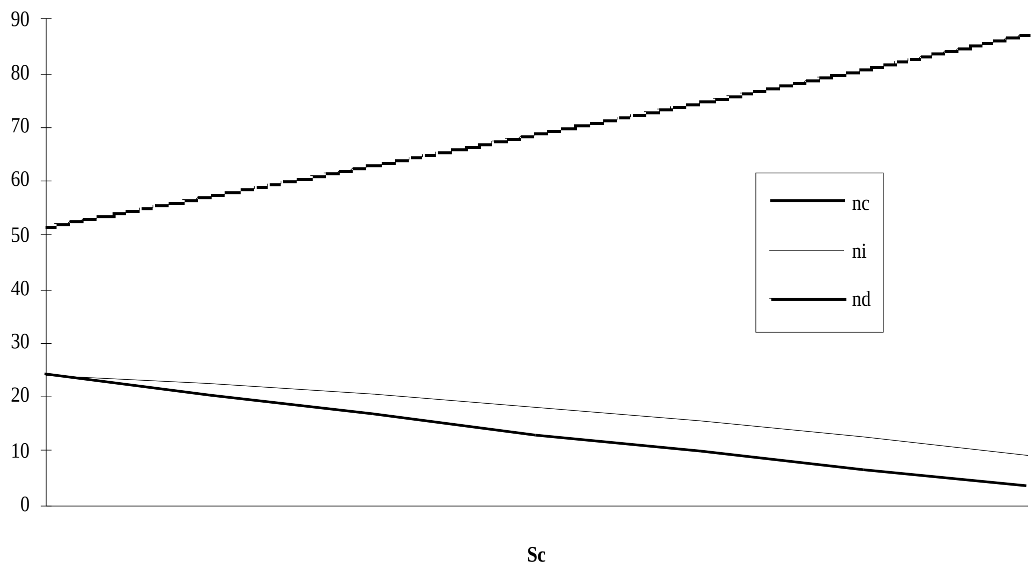


[6] Obviously spillovers which favour firms outside the R&D coalition would create a free-riding problem that may undermine the coalition stability.

As expected, the number of domestic firms increases, whereas those which decide to re-locate their plants abroad sharply decreases.

The impact on the size of the three groups of firms of a subsidy on R&D fixed costs is shown in Figure 3.

Figure 3: *Optimal firm distribution as the subsidy on R&D fixed cost "s_c" increases*



As predicted by the theoretical model, this type of subsidy is counterproductive if the goal is to prevent firms from re-locating their plants in the foreign country.

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