R&D in Cleaner Technology and International Trade

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Summary

We consider a dynamic three-stage game played by two regulator-firm hierarchies to capture the scale and technological effects of opening markets to international trade. Each firm produces one good sold on the market. Firms can invest in R&D in order to lower their fixed emission/output ratio and are regulated with costly public funds. We take the context of sufficiently high market sizes and investment cost parameters. Opening markets to international trade yields more investment in R&D, more production and a lower emission ratio. When the market size is low enough and the investment cost parameter is high enough, pollution in common market is higher than in autarky. International trade reduces the social welfare.

Keywords: R&D, Cleaner technology, Common market, Social welfare

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1.Introduction

This paper studies the combination of the scale and technological effects of opening markets to international trade by means of a dynamic model where there is a possibility to invest in research and development (R&D) while supposing the existence of positive marginal social cost of public funds. We show that opening markets to foreign competitors may increase pollution and always decreases the social welfare.

The relation between free trade and pollution can be explained by three main effects. The scale effect linking pollution to the scale of production and it is expected that international trade increases production and therefore pollution. The composition effect admits that certain dirty industries could relocate in countries with more lenient regulations. The technological effect refers to the possibility that international competition may encourage the innovation and diffusion of cleaner technologies to reduce the pollution intensity.

Copeland and Taylor (1994) develop a static two-country general equilibrium model to isolate the scale, composition and technique effects of international trade on pollution. They show that trade liberalization may raise world pollution. Let's notice that even if they isolate the technique effect, they don't consider the possibility of investment in cleaner production technology because they suppose that it's available and is characterized by abatement possibilities. Antweiler et al. (2001) have conducted empirical tests using data on sulfur dioxide concentrations and have shown that free trade reduces pollution. Reppelin-Hill (1999) empirically demonstrates that a cleaner technology (the electric arc furnace) is diffused more quickly in countries having more open trade regimes. However, these three last papers haven't proved any result concerning the welfare effects of free trade.

Karp et al. (2001) show that autarky is likely to Pareto-dominate free trade in the long run when the environment is fragile, and the result is reversed when the environment is resilient. Walz and Wellisch (1997) highlight that welfare-maximizing governments of exporting countries prefer free trade even if countries subsidize their local industries indirectly through ecological dumping. Péchoux and Pouyet (2003) show that, under incomplete information, international competition generated by the common market enables regulators to reduce the informational rents captured by firms, thereby reinforcing the need to open the markets to international competition.

The most important difference of our approach with respect to the above literature is that firms have the possibility to invest in R&D to lower their emission / output ratio, and we think that the better way to model the investment in cleaner technology is a dynamic model in which the production and innovation decisions are taken at different dates. Our approach is motivated by the fact that in many industries pollution is function of production with no abatement possibilities, and the only way to reduce the pollution intensity is to change the production process i.e. to invest in R&D.

We consider a symmetric three-stage game played by a pair of regulator-firm hierarchies. In the third stage, each firm produces one good sold on the market. In the second stage, firms can invest in R&D in order to lower their fixed emission / output ratio. In the first stage, regulators propose non-cooperatively their contracts which should be accepted by their respective firms while giving the socially optimal levels of production, pollution and R&D. We study the full information context and suppose the existence of positive marginal social cost of public funds ($\lambda>0$). Our objective is to compare the optimal equilibrium values in autarky and common market.

Let's notice the important role played by the positive marginal social cost of public funds because if it's nil the equilibrium values in autarky and common market are equal. In our complete information context, the presence of positive λ means that each regulator gives, in its social welfare function, a higher weight to the profit of its firm with respect to the consumer surplus and the damages caused by pollution. So, when markets are opened to international trade, competition of firms on the common market incites each regulator to increase its production to get a higher share of the common market and this forces them to decrease their emission ratio by increasing their R&D level to have less pollution with respect to the status quo in innovation. However, since the marginal cost of innovation is increasing, the R&D level doesn't rise in a sufficiently quantity which might increase pollution. Consequently, international competition increases production and innovation which might reduce the profit of firms and increase pollution, thus, always reducing the social welfare.

The paper has the following structure. Section 2 presents the basic model when markets are separated. Section 3 treats the case of a common market. Section 4 compares the equilibrium values given by the autarky and common market regimes, and section 5 concludes. Finally, an appendix gathers all the proofs of propositions.

2.Separate markets

Our symmetric model consists of two countries and two firms. Firm *i* located in country *i* is a regional monopoly and produces good *i* in quantity q_i sold in the domestic market with the following inverse demand function : $p_i = a - 2q_i, a > 0$. The size of each market is therefore a/2.

As firm i is a regional monopoly that pollutes the domestic environment, it should be regulated. The regulator can use three types of instruments: a subsidy per-unit of R&D to induce the socially optimal levels of R&D and emission/output ratio, an emission tax per-unit of pollution to induce the socially optimal levels of production and pollution, and a lump sum tax on profit to extract all the profit of the firm because of the positive marginal social cost of public funds. However, computations are very difficult with this first method of regulation. Indeed, the regulator must choose the socially optimal emission tax and subsidy in the first stage given the reaction of the firm which will choose its optimal levels of R&D and production in the second and third stages, respectively. Since our primary objective is to compare the socially optimal equilibrium values of production, innovation, pollution and social welfare in autarky and common market, we consider a second method of regulation which considerably eases computations.

In the first stage, each regulator proposes to his firm a contract (q_i, x_i, T_i) where q_i is the level of production that firm i must produce, x_i is the level of R&D that must be attained by the innovation activity of the firm, and T_i is a monetary transfer inducing the firm to accept this contract. The value of T_i is as such that the net profit of the firm will be at least equal to its reservation utility level which we assume to be equal to zero. When the monetary transfer is positive, the firm receives a subsidy, and when it’s negative, the firm pays a tax. In the second stage, firms invest in R&D, and in the third one, they produce the contracted quantities.

The production process generates pollution and firms can invest in R&D in order to decrease their fixed emission / output ratio. The level x_i of R&D costs kx_i^2, where k>0 is an investment cost parameter.

Denoting the marginal cost of production by θ>0, the profit of firm *i* is $\Pi_i^a = p_i(q_i)q_i - \theta q_i - kx_i^2$, and its net profit is $U_i = \Pi_i^a(q_i, x_i) + T_i$.

By normalizing the emission / output ratio to one without innovation, the pollution ratio of firm *i* is :[1] $e_i = 1 - x_i$, $0 < x_i < 1$.

The emission of pollution of firm *i* is thus : $E_i = e_i q_i$.

Damages caused to country *i* are purely local [2] $D_i = \alpha E_i$, where α>0 expresses the sensitivity of consumers to the quality of the environment.

The production of q_i engenders a consumer surplus in country *i* equal to $CS_i^a = \int_0^{q_i} p_i(t)dt - p_i(q_i)q_i = q_i^2$.

Denoting the marginal social cost of public funds[3] by λ>0, the consumer welfare of country *i* is : $W_i^a = CS_i^a(q_i) - D_i(q_i, x_i) - (1+\lambda)T_i$.

The social welfare of a country is equal to the consumer welfare plus the net profit of the domestic firm : $S_i^a = W_i^a + U_i = CS_i^a(q_i) - D_i(q_i, x_i) + (1+\lambda)\Pi_i^a(q_i, x_i) - \lambda U_i$.

In our complete information setting, each regulator *i* maximizes his social welfare with respect to q_i, x_i and U_i under the rationality constraint of firm *i*. We allow ourselves to express the regulator's problem in function of U_i rather than T_i because these latter are one-to-one related. Since the reservation utility level of firms is assumed to be equal to zero, the regulator chooses the monetary transfer so that the net profit of his firm is nil (U_i =0). Therefore, the social welfare of country *i* becomes:

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[1] We suppose that there is no R&D spillovers between firms because we are able to compare the social welfare in the two market regimes only when this parameter is very small. See d'Aspremont and Jacquemin (1988) for more on this topic.

[2]In this paper, we ignore the possibility of transboundary pollution.

[3] See Laffont (1994) for more on this.

$$S_i^a(q_i, x_i) = CS_i^a(q_i) - D_i(q_i, x_i) + (1+\lambda)\Pi_i^a(q_i, x_i) \quad (1)$$

Expression (1) shows that a higher weight is given to the profit of the domestic firm in the social welfare function, with respect to the consumer surplus and the damages caused by pollution.

The first order condition of the third stage is : $\frac{\partial S_i^a}{\partial q_i} = 0$ (2)

The resolution of (2) yields :

$$q_i^a(x_i) = \frac{\alpha x_i + (1+\lambda)(a-\theta) - \alpha}{2(1+2\lambda)} \quad (3)$$

From expression (3), we have :

$$\frac{\partial q_i^a}{\partial x_i} = \frac{\alpha}{2(1+2\lambda)} > 0 \ \text{ and } \ \frac{\partial q_i^a}{\partial x_j} = 0 \quad (4)$$

Therefore, the quantity produced by a firm increases with the increase of its own R&D level because it reduces its emission / output ratio, and doesn't depend on the R&D level of the other firm because there is no interaction between the two hierarchies.

The first order condition of the second stage is :

$$\frac{dS_i^a}{dx_i} = \frac{\partial q_i}{\partial x_i}\frac{\partial S_i^a}{\partial q_i} + \frac{\partial S_i^a}{\partial x_i} = 0 \quad (5)$$

At the equilibrium, by using (2), equation (5) is simplified and, by using (3), its symmetric[4] solution is :

$$x_i^a = \alpha \frac{(1+\lambda)(a-\theta) - \alpha}{4(1+\lambda)(1+2\lambda)k - \alpha^2} \quad (6)$$

To insure that the numerator of (6) is positive,[5] we need that :

$$(1+\lambda)(a-\theta) > \alpha \Leftrightarrow a > \theta + \frac{\alpha}{1+\lambda} \quad \text{(C.1)}$$

Therefore, our results are true when the market sizes are high enough. Otherwise, regulators will choose not to innovate nor to produce.

We also need that $1 - x_i^a > 0 \Leftrightarrow k > \frac{\alpha(a-\theta)}{4(1+2\lambda)}$ (C.2)

[4] We look for the symmetric equilibrium because the model is symmetric and computations are easier.
[5] Alternatively, we can require that the numerator and denominator are both negative. However, this last condition will be incompatible with the concavity condition of the second stage.

Conditions (C.1) and (C.2) insure the second order condition of the second stage and the positivity of the optimal levels of R&D and production.

3.International trade

When firms produce perfect substitute goods sold in both countries, the inverse demand function becomes : $p = a - (q_i + q_j)$.

The firms profits are : $\Pi_i^{cm} = p(q_i + q_j)q_i - \theta q_i - kx_i^2$.

The total consumer surplus is equally divided between the two symmetric countries :

$$CS_i^{cm} = \frac{1}{2}\left[\int_0^{q_i+q_j} p(t)dt - p(q_i + q_j)(q_i + q_j)\right] = \frac{1}{4}(q_i + q_j)^2$$

As in autarky, firms have a zero net profit and the social welfare of country *i* is :

$$S_i^{cm}(q_i, q_j, x_i) = CS_i^{cm}(q_i, q_j) - D_i(q_i, x_i) + (1+\lambda)\Pi_i^{cm}(q_i, q_j, x_i) \tag{7}$$

The first order condition of the third stage is : $\dfrac{\partial S_i^{cm}}{\partial q_i} = 0$ (8)

Resolving (8), we get :

$$q_i^{cm}(x_i, x_j) = \frac{[(3+4\lambda)x_i - (1+2\lambda)x_j]\alpha + 2(1+\lambda)[(1+\lambda)(a-\theta) - \alpha]}{2(1+\lambda)(2+3\lambda)} \tag{9}$$

From (9), we have :

$$\frac{\partial q_i^{cm}}{\partial x_i} = \frac{(3+4\lambda)\alpha}{2(1+\lambda)(2+3\lambda)} > 0 \quad \text{and} \quad \frac{\partial q_i^{cm}}{\partial x_j} = \frac{-(1+2\lambda)\alpha}{2(1+\lambda)(2+3\lambda)} < 0 \tag{10}$$

When a firm increases its level of R&D, this enables it to produce more because its emission / output ratio is lowered. When the rival firm increases its level of innovation, this lowers its pollution ratio and therefore can produce more, forcing the initial competing firm to reduce its production.

The first order condition of the second stage is :

$$\frac{dS_i^{cm}}{dx_i} = \frac{\partial q_i}{\partial x_i}\frac{\partial S_i^{cm}}{\partial q_i} + \frac{\partial q_j}{\partial x_i}\frac{\partial S_i^{cm}}{\partial q_j} + \frac{\partial S_i^{cm}}{\partial x_i} = 0 \tag{11}$$

The second order condition of the second stage is verified at the equilibrium iff :

$$k > \frac{7 + 21\lambda + 16\lambda^2}{4(1+\lambda)^2(2+3\lambda)^2}\alpha^2 \tag{C.3}$$

Using (8), (9) and (10), the symmetric solution of (11) is :

$$x_i^{cm} = \frac{(4+11\lambda+8\lambda^2)\left[(1+\lambda)(a-\theta)-\alpha\right]\alpha}{4(1+\lambda)^2(2+3\lambda)^2 k-(4+11\lambda+8\lambda^2)\alpha^2} \qquad (12)$$

We also need that $1-x_i^{cm}>0 \Leftrightarrow k>\dfrac{(4+11\lambda+8\lambda^2)(a-\theta)\alpha}{4(1+\lambda)(2+3\lambda)^2}$ (C.4)

Conditions (C.1) and (C.4) imply that the optimal R&D level is positive.

The symmetric expression of (9) is :

$$q_i^{cm} = \frac{1}{2+3\lambda}\left[\alpha x_i^{cm} + (1+\lambda)(a-\theta)-\alpha\right] \qquad (13)$$

4.Separate markets versus common market

The following results are verified under conditions (C.1) to (C.4) which imply that a and k are high enough.

Let's remark that if λ is nil, then expressions (3), (6), (12) and (13) show that the optimal values in autarky and common market are equal.

Proposition 1. *The optimal R&D level and production are higher under common market than under separate markets whereas the emission/output ratio is lower.*

Competition on the common market leads to a higher level of production because of the strategic substituability of goods in the profit functions of firms. Such a raise in production is accompanied by a decrease in the emission ratio realized by increasing the level of R&D to cause less damages to the environment with respect to the status quo in innovation.

Proposition 2. *When a is sufficiently low and k is sufficiently high, pollution in common market is higher than in autarky.*

Opening markets to international trade increases production. To avoid major damages, regulators also increase the R&D level but not in a sufficient amount because R&D expenditures increase rapidly with the innovation level. Thus, pollution, which is the product of the emission/output ratio and production, increases when markets are opened and when a is low enough and k is high enough.

It is therefore expected that, under these conditions, the social welfare decreases when markets are opened to international trade.

Proposition 3. *Opening markets to international trade reduces the social welfare.*

When markets are opened to international trade, both the level of production and R&D increase. The result may be a decrease of the profit of firms, particularly because the marginal cost of innovation is increasing, and a rise of pollution which lead to a diminution of the social welfare.

6.Conclusion

This model captures the scale and technological effects and tries to know the impact of opening markets to international trade on production, R&D, pollution and social welfare.

We consider a dynamic and symmetric three-stage game played by two regulator-firm hierarchies in presence of costly public funds. Each firm produces one good sold on the market and can invest in R&D to lower its fixed emission/output ratio.

Free mobility of goods between countries leads to both more investment in R&D and production, and to a lower emission ratio. When the market sizes are sufficiently low and the investment cost parameter is sufficiently high, international trade leads to an increase of pollution. The social welfare is always greater when markets are separated than when there is a common market. Indeed, when markets are opened to international trade, production and innovation increase which may reduce the profit of firms and increase pollution, thus, reducing the social welfare. Let's point out that all these results are valid when the market sizes of countries and the investment cost parameter are high enough.

A possible extension of this work is to introduce asymmetric information between the regulators and their respective firms concerning their production costs or R&D activity. Incomplete information may change our final result because competition of firms on the common market may reduce their informational rents and therefore increases the social welfare. Another extension, which could imply difficult computations, is to consider the existence of transboundary pollution between countries.

Appendix

A)Proof of Proposition 1

Using expressions (6) and (12), we show that $x_i^{cm} - x_i^a > 0$, which implies that $e_i^{cm} < e_i^a$.

Since $x_i^{cm} > x_i^a$, from expressions (3) and (13), we also have $q_i^{cm} > q_i^a$.

B)Proof of Proposition 2

Consider the function $f(x_i) = (1 - x_i)[\alpha x_i + (1+\lambda)(a-\theta) - \alpha]$.

We have : $f'(x_i) > 0 \Leftrightarrow x_i < x^1 = \dfrac{2\alpha - (1+\lambda)(a-\theta)}{2\alpha}$.

If (1+λ)(a-θ)<2α, then $f'(x_i) > 0, \forall\, x_i < x^1$ with $x^1 > 0$.

Using the expressions of x_i^{cm} and x^1, we show that :

$$x_i^{cm} - x^1 < 0 \Leftrightarrow k > k^1 = \frac{(4 + 11\lambda + 8\lambda^2)\alpha^2 (a-\theta)}{4(1+\lambda)(2+3\lambda)^2 [2\alpha - (1+\lambda)(a-\theta)]}$$

Therefore, if (1+λ)(a-θ)<2α $\Leftrightarrow a < \theta + \dfrac{2\alpha}{1+\lambda}$ and $k > k^1$, then $0 < f(x_i^a) < f(x_i^{cm})$, implying that :

$$E_i^{cm} = \frac{f(x_i^{cm})}{2+3\lambda} > \frac{f(x_i^a)}{2+3\lambda} > \frac{f(x_i^a)}{2(1+2\lambda)} = E_i^a$$

Thus, when a is low enough and k is high enough, opening markets to international trade increases pollution.

C)Proof of Proposition 3

Using expressions (1) and (7), the equilibrium social welfare of country *i* can be written as :

$$S_i = -(1+2\lambda)(q_i(x_i))^2 + [\alpha x_i + (1+\lambda)(a-\theta) - \alpha] q_i(x_i) - (1+\lambda) k x_i^2$$

Using expressions (3) and (13) :

$$S_i = d[\alpha x_i + (1+\lambda)(a-\theta) - \alpha]^2 - (1+\lambda) k x_i^2$$

where $d^{a} = \frac{1}{4(1+2\lambda)}$ in autarky, and $d^{cm} = \frac{1+\lambda}{(2+3\lambda)^{2}}$ in common market. It's easy to verify that $d^{a} > d^{cm}$.

Consider the function $g(x_i) = \frac{1+\lambda}{(2+3\lambda)^{2}}\left[\alpha x_i + (1+\lambda)(a-\theta) - \alpha\right]^{2} - (1+\lambda)kx_i^{2}$.

Using conditions (C.1) and (C.2), $g'(x_i) < 0 \Leftrightarrow x_i > x^{2} = \frac{\left[(1+\lambda)(a-\theta)-\alpha\right]\alpha}{(2+3\lambda)^{2}k-\alpha^{2}}$.

Using the expression of x_i^{a}, we show that $x_i^{a} - x^{2} > 0$.

We have : $S_i^{cm} = g(x_i^{cm}) < g(x_i^{a}) = d^{cm}\left[\alpha x_i^{a} + (1+\lambda)(a-\theta) - \alpha\right]^{2} - (1+\lambda)k(x_i^{a})^{2} < S_i^{a}$.

Therefore, opening markets to international trade reduces social welfare.

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(lix) This paper was presented at the ENGIME Workshop on "Mapping Diversity", Leuven, May 16-17, 2002

(lx) This paper was presented at the EuroConference on "Auctions and Market Design: Theory, Evidence and Applications", organised by the Fondazione Eni Enrico Mattei, Milan, September 26-28, 2002

(lxi) This paper was presented at the Eighth Meeting of the Coalition Theory Network organised by the GREQAM, Aix-en-Provence, France, January 24-25, 2003

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(lxv) This paper was presented at the EuroConference on "Auctions and Market Design: Theory, Evidence and Applications" organised by Fondazione Eni Enrico Mattei and sponsored by the EU, Milan, September 25-27, 2003

(lxvi) This paper has been presented at the 4th BioEcon Workshop on "Economic Analysis of Policies for Biodiversity Conservation" organised on behalf of the BIOECON Network by Fondazione Eni Enrico Mattei, Venice International University (VIU) and University College London (UCL) , Venice, Italy 28-29, 2003

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