R&D IN CLEANER TECHNOLOGY AND INTERNATIONAL TRADE

by

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Abstract : We consider a symmetric three-stage game played by two regulator-firm hierarchies to capture the scale and technology effects. 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.

Opening markets to international trade leads to both more investment in R&D and production. When the sensitivity of consumers to the environment and the investment cost parameter are sufficiently high, pollution under common market is higher than under autarky. The social welfare when markets are separated is higher than when there is international trade.

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1.Introduction

This paper studies the combination of the scale and technology effects, and whether R&D possibilities in cleaner technologies encourage opening national markets to foreign competitors.

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 pollution.

Copeland and Taylor (1994) develop a simple static two-country general equilibrium model. They show that trade is always welfare-improving, even when it raises pollution levels. Karp, Sacheti and Zhao (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 (2001) 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.

To our knowledge, there is no published theoretical work that has tried to capture the technological effect. Reppelin-Hill (1999) empirically demonstrates that a cleaner technology (the electric arc furnace) is diffused more quickly in countries having more open trade regimes.

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 marginal social cost of public funds. Our objective is to compare the optimal equilibrium values under autarky and common market.

We show that international trade leads to more investment in R&D and to more production. As a consequence, when the sensitivity of consumers to the environment and the investment cost parameter are high enough, trade liberalization engenders more pollution. The social welfare is always greater when markets are separated. The intuition behind this result is that when markets are opened to competition, production increases which may reduce the profit of firms and increase pollution, thus, reducing 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

We consider a three-stage game played by two regulator-firm hierarchies. 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, x^i is the level of R&D, and T^i is a monetary transfer inducing the firm to accept this contract. Alternately, the regulator may use a per-unit tax on pollution to induce the socially desired levels of pollution and production, and the monetary transfer may be the investment cost. We choose to resolve the problem in terms of the level of production because it is mathematically easier to do.

In the second stage, firms can invest in R&D in order to decrease their emission/output ratio. The level x^i of R&D costs $kx^{i2}, k > 0$.

In the third stage, firm i located in country i produces good i in quantity q^i sold in the domestic market having the following inverse demand function : $p^i = a - 2q^i, a > 0$.

Denoting the marginal cost of production by θ>0, the profit of firm i is : $\Pi^{ia} = p^i(q^i)q^i - \theta q^i - kx^{i2}$.

By normalizing the emission/output ratio to one when there is no innovation, the emission of pollution of firm i is $E^i = (1 - x^i)q^i, 0 < x^i < 1$.

Damages caused to country i are purely local[1] : $D^i = \alpha E^i$, α>0.

The production of q^i engenders a consumer surplus in country i equal to $CS^{ia}(q^i) = q^{i2}$.

The social welfare of a country is equal to the consumer surplus minus damages plus the profit of the domestic firm pondered by (1+λ) :

$$S^{ia} = CS^{ia}(q^i) - D^i(q^i, x^i) + (1+\lambda)\Pi^{ia}(q^i, x^i) \quad (1)$$

where λ>0 is the marginal social cost of public funds. Therefore, a higher weight is given to the profit of the domestic firm in the social welfare function, with respect to the consumer welfare.

The first order condition of the third stage is :

$$S^{ia}_{q^i} = CS^{ia}_{q^i} - D^i_{q^i} + (1+\lambda)\Pi^{ia}_{q^i} = 0 \quad (2)$$

The resolution of (2) yields :

$$q^{ia}(x^i) = \frac{\alpha x^i + (1+\lambda)(a-\theta) - \alpha}{2(1+2\lambda)} \quad (3)$$

From expression (3), we have :

$$q^{ia}_{x^i} = \frac{\alpha}{2(1+2\lambda)} > 0 \text{ and } q^{ia}_{x^j} = 0 \quad (4)$$

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.

Using (2), the first order condition of the second stage is reduced to :

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

$$S^{ia}_{x^i} = -D^i_{x^i} + (1+\lambda)\Pi^{ia}_{x^i} = 0 \qquad (5)$$

The symmetric solution of equation (5) is :

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

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

$$(1+\lambda)(a-\theta) > \alpha \qquad (C.1)$$

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

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 there is free mobility of goods between countries, firms produce perfect substitute goods sold in both countries with the following inverse demand function : $p = a - (q^i + q^j)$.

The firms profits are : $\Pi^{icm} = p(q^i, q^j)q^i - \theta q^i - kx^{i2}$.

The total consumer surplus is equally divided between the two symmetric countries : $CS^{icm} = \dfrac{1}{4}(q^i + q^j)^2$.

The social welfare of country i is :

$$S^{icm} = CS^{icm}(q^i, q^j) - D^i(q^i, x^i) + (1+\lambda)\Pi^{icm}(q^i, q^j, x^i) \qquad (7)$$

The first order condition of the third stage is :

$$S^{icm}_{q^i} = CS^{icm}_{q^i} - D^i_{q^i} + (1+\lambda)\Pi^{icm}_{q^i} = 0 \qquad (8)$$

Resolving (8), we get :

$$q^{icm}(x^i, x^j) = \frac{\left[(3+4\lambda)x^i - (1+2\lambda)x^j\right]\alpha + 2(1+\lambda)\left[(1+\lambda)(a-\theta)-\alpha\right]}{2(1+\lambda)(2+3\lambda)} \qquad (9)$$

From (9), we have :

$$q^{icm}_{x^i} = \frac{(3+4\lambda)\alpha}{2(1+\lambda)(2+3\lambda)} > 0 \text{ and } q^{icm}_{x^j} = \frac{-(1+2\lambda)\alpha}{2(1+\lambda)(2+3\lambda)} < 0 \qquad (10)$$

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.

By using (8), the first order condition of the second stage is reduced to :

$$S_{x^i}^{icm} = q_{x^i}^{jcm}\left[CS_{q^j}^{icm} + (1+\lambda)\Pi_{q^j}^{icm}\right] - D_{x^i}^{i} + (1+\lambda)\Pi_{x^i}^{icm} = 0 \qquad (11)$$

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

$$k > \frac{1}{4(1+\lambda)}\left[q_{x^i}^{icm}(2\alpha - (1+2\lambda)q_{x^i}^{jcm}) + (q_{x^i}^{jcm})^2\right] \qquad (C.3)$$

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

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

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

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

The symmetric expression of (9) is :

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

4.Separate markets versus common market

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

Proposition 1. *The optimal R&D level and production are higher under common market than under separate markets.*

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 an increase in production is accompanied by an increase in the level of R&D to cause less damages to the environment with respect to the status quo in innovation.

Proposition 2. *When α and k are sufficiently high, pollution in the common market regime is higher than in the autarky regime.*

Opening markets to the 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 α and k are 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 and an increase of pollution which lead to a diminution of the social welfare.

6.Conclusion

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

We consider a symmetric three-stage game played by two regulator-firm hierarchies. 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. When the sensitivity of consumers to the environment and the investment cost parameter are 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 social welfare.

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. Another extension, which could imply difficult computations, is to consider the possibility of cross-borders pollution between countries.

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Appendix

A)Proof of Proposition 1

Using expressions (6) and (12), we show that $x^{icm} - x^{ia}$ >0.

Since $x^{icm} > x^{ia}$, from expressions (3) and (13), we also have $q^{icm} > q^{ia}$.

B)Proof of Proposition 2

Consider the function $f(x^i) = (1 - x^i)\left[\alpha x^i + (1+\lambda)(a-\theta) - \alpha\right]$.

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 $f'(x^i) > 0, \forall x^i < x_1$.

Using the expressions of x^{icm} and x_1, we show that :

$$x^{icm} - x_1 < 0 \Leftrightarrow k > k_1 = \frac{(4+11\lambda+8\lambda^2)\alpha^2(1+\lambda)(a-\theta)}{4(1+\lambda)^2(2+3\lambda)^2\left[2\alpha - (1+\lambda)(a-\theta)\right]}$$

Therefore, if (1+λ)(a-θ)<2α and $k > k_1$, then $0 < f(x^{ia}) < f(x^{icm})$, implying that :

$$E^{icm} = \frac{f(x^{icm})}{2+3\lambda} > \frac{f(x^{ia})}{2+3\lambda} > \frac{f(x^{ia})}{2(1+2\lambda)} = E^{ia}$$

Thus, when α and k are 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 :

$$S^i = -(1+2\lambda)q^{i2}(x^i) + \left[\alpha x^i + (1+\lambda)(a-\theta) - \alpha\right]q^i(x^i) - (1+\lambda)kx^{i2}$$

Using expressions (3) and (13) :

$$S^i = d\left[\alpha x^i + (1+\lambda)(a-\theta) - \alpha\right]^2 - (1+\lambda)kx^{i2}$$

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

Consider the function $g(x^i) = \dfrac{1+\lambda}{(2+3\lambda)^2}\left[\alpha x^i + (1+\lambda)(a-\theta) - \alpha\right]^2 - (1+\lambda)kx^{i2}$.

Using conditions (C.1) and (C.2), $g'(x^i) < 0 \Leftrightarrow x^i > x_2 = \dfrac{\left[(1+\lambda)(a-\theta) - \alpha\right]\alpha}{(2+3\lambda)^2 k - \alpha^2}$.

Using the expression of x^{ia}, we show that $x^{ia} - x_2 > 0$.

We have : $S^{icm} = g(x^{icm}) < g(x^{ia}) = d^{cm}\left[\alpha x^{ia} + (1+\lambda)(a-\theta) - \alpha\right]^2 - (1+\lambda)kx^{ia2} < S^{ia}$.

Therefore, opening markets to international trade reduces social welfare.