Transboundary Pollution, R&D Spillovers and International Trade

Slim Ben Youssef

NOTA DI LAVORO 39.2003

APRIL 2003

KNOW – Knowledge, Technology, Human Capital

Slim Ben Youssef, *Université de Tunis El Manar, Tunisia*

Transboundary Pollution, R&D Spillovers and International Trade

Summary

We consider a non-cooperative symmetric three-stage game played by a pair of 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. The production process generates pollution characterized by a fixed emission/output ratio, and crosses the borders. Firms can invest in R&D in order to lower their emission ratio, and this activity is characterized by positive R&D spillovers (β).

We show that R&D spillovers and the competition of firms on the common market help non-cooperating countries to better internalize transboundary pollution.

When the R&D spillover increases, pollution decreases in most cases, and increases in some others. However, the social welfare improves with β.

Opening markets to international trade leads to both more investment in R&D and more production, and to a lower emission ratio. In most cases, pollution in common market is lower than in autarky, implying a greater social welfare. Nevertheless, in some other cases, international trade increases pollution and therefore reduces the social welfare.

Keywords: Transboundary pollution, R&D spillovers, Common market, Social welfare

JEL: D62, F12, O32

Address for correspondence:

Slim Ben Youssef
Université de Tunis El Manar
Faculté des Sciences Economiques et de Gestion de Tunis
Campus Universitaire
1050 Tunis
Tunisia
E-mail: slim.benyoussef@gnet.tn

1. Introduction

We develop a dynamic theoretical model to show how R&D spillovers and the competition of firms on the common market help non-cooperating countries to internalize transboundary pollution. This model also captures the scale and technological effects of opening markets to international trade, and shows that, in most cases, free mobility of goods among countries reduces pollution and improves the social welfare. Thus, this work is related to the literature on transboundary pollution and to the one on free trade and the environment. To our knowledge, there is no published theoretical work that studies transboundary pollution in the context of R&D possibilities and / or studies the technological effect of free trade in presence of transfrontier pollution, while taking into account the impact on the social welfare.

Examples of damages engendered by tranfrontier pollution are the ozone layer depletion and global warming which are caused by the total emissions of gazes such as the carbon dioxide. Transboundary pollution is therefore a negative externality among countries which usually does not lead non-cooperating countries to the Pareto-optimality. However, some authors have shown that non-cooperating governments can reach the first best under some conditions (Hoel (1997), Zagonari (1998)). Other studies have been interested in the effect of asymmetric information on transboundary externalities (Bac (1996), Petrakis and Xepapadeas (1996), Mansouri and Ben Youssef (2000)).

The relation between international 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 free 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 (1995) show that free trade may raise world pollution, and because pollution crosses the borders, uncoordinated regulation of pollution at the national level does not eliminate all market failures, and consequently free trade does not necessarily raise welfare. Fernandez (2002) examines empirically the effects of trade liberalization on transboundary water pollution between the United States and Mexico. She shows that trade liberalization gives incentives to use wastewater as input to produce the traded cotton, thus reducing pollution. 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. Many papers (Copeland and Taylor (1994), Reppelin-Hill (1999), Antweiler et al. (2001)) highlight the technological effect but they don't consider transboundary pollution and don't prove any result concerning the welfare effects of free trade.

This paper differs from the existing literature by studying a three-stage game in which R&D is carried out to reduce the emissions per-unit of production, in the context of R&D spillovers and transboundary pollution. This model also captures the scale and technological effects and tries to answer the question of whether opening markets to international trade reduces pollution and increases the social welfare.

We consider a non-cooperative and symmetric three-stage game played by two regulator-firm hierarchies. In the third stage, each firm produces one good sold on the market. The production process generates pollution characterized by a fixed emission/output ratio, and crosses the borders. In the second stage, firms can invest in R&D in order to lower their emission ratio. As in D'Aspremont and Jacquemin (1988) where firms invest in R&D to lower their per-unit production cost, this innovation activity is characterized by positive R&D spillovers (β). In the first stage, regulators propose non-cooperatively their contracts which should be accepted by their respective firms while giving the non-cooperative socially optimal levels of pollution (or production) and R&D. We study the complete information context. Our objective is to assess the role of R&D spillovers and the opening of markets in the control of transboundary pollution, and to compare the equilibrium values in autarky and common market. We hope to contribute to the understanding of the interaction between the scale and technological effects in case of transboundary pollution.

We show that without R&D spillover (β=0), transboundary pollution is not internalized in the autarky regime. The higher R&D spillovers are, the higher is the proportion of transboundary pollution internalized by non-cooperating countries. Consequently, in most cases, pollution decreases with the R&D spillover whereas the social welfare increases. Surprisingly, in some other cases, pollution increases with β. Moreover, opening markets to international trade helps countries to better internalize transboundary pollution through firms' competition on the common market.

International competition leads to both more investment in R&D and more production, and to a lower emission ratio. When the sensitivity of consumers to the environment is sufficiently low, pollution in common market is lower than in autarky, implying a greater social welfare. Nevertheless, when the sensitivity of consumers to the environment and the investment cost parameter are high enough , pollution in common market is higher than in autarky; thus, the non-internalized transboundary pollution may be greater, even if opening markets enables to better internalize the transfrontier externality; moreover, the increase of production and innovation may decrease the profit of firms, leading to a diminution of the social welfare.

The paper is organized as follows. Section 2 presents the basic model in autarky, resolves it and exhibits the role of the R&D spillovers for the internalization of transboundary pollution. Section 3 deals with the case where markets are opened to international trade and shows how this contributes to internalize transborder pollution. Section 4 compares the equilibrium in autarky and common market, and section 5 gives some comparative static about the R&D spillover parameter. Finally, section 6 concludes. All the proofs of the propositions are gathered in the appendix.

2. Autarky

We consider a symmetric model consisting 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 market size of each country is therefore a / 2.

The production process generates pollution and firms can invest in R&D in order to lower their fixed emission / output ratio. The level x_i of R&D costs $kx_i^2, k > 0$.

If we denote the marginal cost of production by θ>0, the profit of firm *i* is: $\Pi_i^a = p_i(q_i)q_i - \theta q_i - kx_i^2$.

The innovation activity carried out by the firms is characterized by positive externalities which imply that a proportion β of each firm's R&D level gratuitously spillovers to the other firm. Therefore, the direct external effect of firm *j*'s R&D level is to lower firm *i*'s emission / output ratio. This can be made possible by scientific communications, scientific exchanges or intelligence activities, which we assume have negligible costs. By normalizing the emissions per-unit of production to one without innovation, the emission / output ratio of firm *i* is :

$$e_i = 1 - x_i - \beta x_j, 0 \le \beta < 1, 0 < x_i + \beta x_j < 1$$

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

There are also negative externalities between countries through transborder pollution. Damages caused to country *i* are: $D_i = \alpha E_i + \gamma E_j, \alpha > 0, \gamma > 0$.

Notice that even when α and γ are different, the model still remains symmetric because these parameters are the same for the two countries. This damage function can explain a pure transfrontier pollution problem when α=d(1-t) and γ=dt, where 0<t<1 is the proportion of pollution of firm *j* exported to country *i*. It can also explain an international environmental problem, when α=γ, because damages in one country become a function of the total pollution. To explain how transfrontier pollution can be internalized, we will separate the negative effect of the foreign pollution from the one of the home pollution by working with α and γ separately up to section 3, and then, to facilitate our computations, we will assimilate γ to α.

The consumer surplus in country i engendered by the consumption of q_i is $CS_i^a = \int_0^{q_i} p_i(t)dt - p_i(q_i)q_i = q_i^2$.

Since firm i is a regional monopoly that pollutes the environment, it should be regulated. The regulator can use two types of instruments : an emission tax per-unit of pollution to induce the non-cooperative socially optimal levels of production and pollution, and a subsidy per-unit of R&D to induce the non-cooperative socially optimal levels of R&D and emission / output ratio. Unfortunately, computations are not easy to do with this method of regulation. Indeed, the regulator must choose both the non-cooperative socially optimal emission tax and subsidy in the first stage given the reaction of the firm which will choose its non-cooperative optimal levels of R&D and production in the second and third stages, respectively. So, we consider another method of regulation which eases computations.

In the first stage, each regulator offers to his firm a contract (q_i, x_i, T_i) where q_i and x_i are the levels of production and innovation to be attained by firm *i*, 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. Let's notice that this monetary transfer will not appear in the social welfare function because it is a pure transfer from the regulator to the firm i.e. we suppose that there is no marginal social cost of public funds.[1] In the second stage, firms invest in R&D, and in the third one, they produce the contracted quantities.

The social welfare of a country is equal to the consumer surplus minus damages plus the profit of the firm :

$$S_i^a(q_i, q_j, x_i, x_j, \boldsymbol{b}) = CS_i^a(q_i) - D_i(q_i, q_j, x_i, x_j, \boldsymbol{b}) + \Pi_i^a(q_i, x_i) \tag{1}$$

or written otherwise :

$$S_i^a = q_i^2 - \boldsymbol{a}(1 - x_i - \boldsymbol{b}x_j)q_i - \boldsymbol{g}(1 - x_j - \boldsymbol{b}x_i)q_j + (a - 2q_i)q_i - \boldsymbol{q}q_i - kx_i^2 \tag{2}$$

[1] The resolution of the autarky and common market cases is possible if we suppose the existence of positive marginal social cost of public funds. Unfortunately, the comparison of the equilibrium values in the two market regimes becomes very difficult to do.

Expression (2) shows that in the third stage when regulator i chooses his production quantity q_i, the pollution coming from country j is not internalized. This is general for static models characterized by a linear damage function with respect to the total pollution, or a separable one with respect to the pollution remaining at home and the one received from the other country.[2] However, in the second stage when regulator i chooses his level of R&D x_i, transboundary pollution is partially internalized if there is R&D spillovers ($\beta \neq 0$). The higher the positive externality is, the greater proportion of the negative externality is internalized.

The first order condition of the third stage is : $\frac{\partial S_i^a}{\partial q_i} = 0$ (3)

The resolution of (3) gives :

$$q_i^a = \frac{1}{2}\left[a - \theta - \alpha(1 - x_i - \beta x_j)\right] \tag{4}$$

From (4), we have :

$$\frac{\partial q_i^a}{\partial x_i} = \frac{\alpha}{2} \quad \text{and} \quad \frac{\partial q_i^a}{\partial x_j} = \frac{\alpha\beta}{2} \tag{5}$$

Therefore, the quantity produced by a firm increases with its own R&D level, and with the R&D level of the other firm in case of positive spillovers, because they reduce its emission / output ratio.

Using equality (3), the first order condition of the second stage is reduced to :

$$\frac{dS_i^a}{dx_i} = \frac{\partial q_j}{\partial x_i}\frac{\partial S_i^a}{\partial q_j} + \frac{\partial S_i^a}{\partial x_i} = 0 \tag{6}$$

The symmetric[3] solution of (6), using (4) and (5), is :

$$x_i^a = \frac{(\alpha + \beta\gamma)(a - \theta) - \alpha(\alpha + 2\beta\gamma)}{4k - (1 + \beta)\alpha(\alpha + 2\beta\gamma)} \tag{7}$$

Expression (7) confirms the fact that without R&D spillovers, transboundary pollution is completely non internalized. The higher β is, the greater proportion of transboundary pollution is internalized. Part of this negative externality is

---

[2] If the damages are not linear nor separable, the transboundary pollution is partially non-internalized.

[3] We look for the symmetric equilibrium because, first, the model is symmetric and, second, computations are easier.

internalized when a country chooses its level of R&D, because such a choice will affect the emission ratio of the firm of the other country in case of R&D spillovers, which will, in turn, affect the pollution received.

This strategic interaction with transboundary pollution recalls the analysis of Santore et al. (2001), even though their model is drastically different from the one of this paper. They examine the strategic behavior of state-level utility regulators when pollution spillovers among countries are asymmetric and show that strategic behavior is possible because a regulator's environmental policy indirectly affects the price of permits and, therefore, abatement in other states.

To assure that the quantity given by (7) is positive, we need that :

$$a - \boldsymbol{q} > \frac{\boldsymbol{a}(\boldsymbol{a} + 2\boldsymbol{bg})}{\boldsymbol{a} + \boldsymbol{bg}} \quad \text{(C.1)} \qquad , \quad \text{and} \quad k > \frac{1}{4}(1 + \boldsymbol{b})\boldsymbol{a}(\boldsymbol{a} + 2\boldsymbol{bg}) \qquad \text{(C.2)}$$

This last inequality guarantees the second order condition of equation (6).

We also need that $(1 + \boldsymbol{b})x_i^a < 1 \Leftrightarrow k > \frac{1}{4}(1 + \boldsymbol{b})(\boldsymbol{a} + \boldsymbol{bg})(a - \boldsymbol{q})$ (C.3)

The symmetric production quantities are given by (4) :

$$q_i^a = \frac{1}{2}\left[(1 + \boldsymbol{b})\boldsymbol{a}x_i^a + (a - \boldsymbol{q}) - \boldsymbol{a}\right] \qquad (8)$$

Condition (C.1) guarantees that the above quantities are positive.

3. Common market

When markets are opened to international trade, the inverse demand function of the perfect substitute goods produced by firms becomes : $p = a - (q_i + q_j)$. The size of the integrated market is a.

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

The total consumer surplus is equally divided between the two symmetric countries : $CS_i^{cm} = \frac{1}{2}\left[\int_0^{q_i+q_j} p(t)dt - p(q_i + q_j)(q_i + q_j)\right] = \frac{1}{4}(q_i + q_j)^2$.

The social welfare of country *i* is :

$$S_i^{cm}(q_i, q_j, x_i, x_j, \boldsymbol{b}) = CS_i^{cm}(q_i, q_j) - D_i(q_i, q_j, x_i, x_j, \boldsymbol{b}) + \Pi_i^{cm}(q_i, q_j, x_i) \qquad (9)$$

The first order condition of the third stage is : $\frac{\partial \Pi_i^{cm}}{\partial q_i} = 0$ (10)

The resolution of (10) is :

$$q_i^{cm} = \frac{1}{2}\left[\frac{1}{2}(3-\beta)\alpha x_i + \frac{1}{2}(3\beta-1)\alpha x_j + (a-\theta) - \alpha\right] \qquad (11)$$

From (11), we have :

$$\frac{\partial q_i^{cm}}{\partial x_i} = \frac{1}{4}(3-\beta)\alpha \quad \text{and} \quad \frac{\partial q_i^{cm}}{\partial x_j} = \frac{1}{4}(3\beta-1)\alpha \qquad (12)$$

When a firm increases its level of R&D, this has two opposite effects on its production. The first is positive and enables it to produce more because its emission/output ratio is lowered. The second is negative, because through R&D spillovers the rival firm has a lower emission ratio enabling it to produce more on the common market, which forces the initial firm to reduce its production. The combination of these two effects always increases production ($\partial q_i^{cm} / \partial x_i > 0$); however, such an increase is less important with higher R&D externalities ($\partial^2 q_i^{cm} / \partial x_i \partial \beta < 0$).

When the rival firm increases its level of innovation, it affects the production of the firm both positively and negatively. Indeed, through β, the firm has a lower emission/output ratio which enables it to produce more. But since the rival firm has a lower pollution ratio it can produce more, forcing the firm to reduce its production. The first positive effect dominates when β is high enough ($\partial q_i^{cm} / \partial x_j > 0 \Leftrightarrow \beta > 1/3$).

By using (10), the first order condition of the second stage is reduced to :

$$\frac{dS_i^{cm}}{dx_i} = \frac{\partial q_j}{\partial x_i}\frac{\partial \Pi_i^{cm}}{\partial q_j} + \frac{\partial \Pi_i^{cm}}{\partial x_i} = 0 \qquad (13)$$

Using (11) and (12), the symmetric solution of (13) is :

$$x_i^{cm} = \frac{2(\alpha+\beta\gamma)(a-\theta) - \alpha\left[2\alpha + (5\beta-1)\gamma\right]}{8k - (1+\beta)\alpha\left[2\alpha + (5\beta-1)\gamma\right]} \qquad (14)$$

In common market, transboundary pollution is internalized through two channels : R&D spillovers and competition of firms on the common market. Indeed, when country *i* chooses its level of innovation this affects the emission ratio of its firm and therefore its production and the production of the competing firm, which in turn affects the pollution received by country *i*. Therefore, opening the markets to international competition helps non-cooperating countries to better internalize transboundary pollution, when R&D possibilities are considered.

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

$$k > \frac{1}{4}(3\boldsymbol{b}-1)\boldsymbol{bag} + \frac{1}{16}(3\boldsymbol{b}^2 - 6\boldsymbol{b} + 7)\boldsymbol{a}^2 \quad \text{(C.4)}$$

The solution given by (14) is positive when :

$$a - \boldsymbol{q} > \frac{\boldsymbol{a}\left[2\boldsymbol{a} + (5\boldsymbol{b}-1)\boldsymbol{g}\right]}{2(\boldsymbol{a}+\boldsymbol{bg})} \quad \text{(C.5)} \quad , \quad \text{and} \quad k > \frac{1}{8}(1+\boldsymbol{b})\boldsymbol{a}\left[2\boldsymbol{a} + (5\boldsymbol{b}-1)\boldsymbol{g}\right] \quad \text{(C.6)}$$

We also need that $(1+\boldsymbol{b})x_i^{cm} < 1 \Leftrightarrow \; k > \frac{1}{4}(1+\boldsymbol{b})(\boldsymbol{a}+\boldsymbol{bg})(a-\boldsymbol{q})$ (C.7)

The symmetric production quantities are given by (11) :

$$q_i^{cm} = \frac{1}{2}\left[(1+\boldsymbol{b})\boldsymbol{a}x_i^{cm} + (a-\boldsymbol{q}) - \boldsymbol{a}\right] \quad (15)$$

A sufficient condition for the above production quantities to be positive is :

$$(a\text{-}\theta) > \alpha \quad \text{(C.8)}$$

Notice that in both market regimes, countries can implement the non-cooperative socially optimal allocations by using two instruments: a subsidy per-unit of R&D to induce the desired level of innovation, and a tax per-unit of pollution to induce the desired levels of pollution and production.

In the remaining of the paper, to simplify our computations, we will replace γ by α.

In the following propositions, we suppose that conditions (C.1) to (C.3) and (C.4) to (C.8) are verified for the autarky and common market regimes, respectively. Notice that these conditions, when γ=α, imply that α is sufficiently low and k is sufficiently high. Indeed, when the sensitivity of consumers to the environment is high, the investment in R&D may be too high when it does not costs much, leading to a negative emission ratio which has no economic meaning.

4. Common market versus autarky

In the previous sections we have showed that opening markets to international trade better internalizes transborder pollution. This suggests that the levels of R&D and production are higher in common market. But what about emissions and social welfare ?

Proposition 1. *The R&D level and production are higher in common market than in autarky, whereas the emission/output ratio is lower.*

Opening markets to international trade better internalizes transboundary pollution, which leads to a higher R&D level than in autarky. Consequently, the emission ratio is lower, enabling firms to produce more in common market.[4]

It's interesting to emphasize that these differences are due to the second stage of R&D because if the innovation levels were equal in autarky and common market, then from (8) and (15), productions, and thus and all the equilibrium values, would be equal.

Proposition 2. *International trade reduces pollution when α is sufficiently low, and increases it when α and k are high enough.*

When we increase the R&D level, the emission per-unit of production decreases and production increases, which, in most cases, lowers pollution implying that pollution in common market is lower than in autarky. However, when α is sufficiently high, the R&D level provided to internalize pollution is important and the emission ratio is low; when markets are opened to international trade, the

[4] Let's notice that if there was no negative externality between countries, then the equilibrium values in autarky and common market would be identical. Indeed, if γ=0, expressions (7) and (14) show that the R&D levels are equal which implies that all the other equilibrium values are equal in the two market regimes.

emission/output ratio slightly decreases when k is high enough because the marginal cost of R&D is increasing, whereas production significantly increases, leading to an increase of pollution. Thus, the better internalization of transborder pollution engendered by the competition of firms on the common market is materialized by an increase in the R&D level which is a choice variable, and does not necessarily imply a decrease of pollution. This implies that the non-internalized transborder pollution may be greater in common market even if opening markets enables to capture a greater proportion of the transfrontier externality.

Proposition 3. *International trade increases the social welfare when α is sufficiently low, and decreases it when α and k are high enough.*

The results of proposition 3 are in concordance with those of propositions 1 and 2. Indeed, in most cases, opening markets to international competition increases production and innovation and decreases pollution, leading to an increase in social welfare. Nevertheless, when α and k are sufficiently high, pollution in common market is higher than in autarky ; moreover, international trade increases production and innovation which may reduce the profit of firms; the combination of these effects leads to a lower social welfare in common market. Since this last situation happens under very restrictive conditions[5], we can say that, in general, opening markets to international trade reduces pollution and improves the social welfare.

5. The effect of R&D spillovers

So far, we have shown that a higher β helps non-cooperating countries to internalize a greater proportion of transborder pollution. It is therefore expected that when the R&D spillover increases, pollution and the emission/output ratio decrease

[5] We recall that the equilibrium conditions imply that α is sufficiently low. So, when, in addition, α is high enough, the set to which belongs α is very restricted.

whereas the social welfare increases. The following proposition will confirm these predictions in almost all the cases, and shows when we have unexpected results.

Proposition 4. *i)When* ***a*** *is sufficiently low, both the equilibrium levels of R&D and production increase with* ***b****, whereas the emission/output ratio decreases with* ***b****. However, when* ***a*** *and k are sufficiently high, we have the opposite results.*

ii)In most cases pollution decreases with ***b****, and it increases only when* ***a*** *is neither too high nor too low and k is sufficiently high.*

iii)The social welfare increases with the R&D spillover.

We know that when β increases, a greater proportion of transboundary pollution is internalized by non-cooperating regulators, which in most cases leads to a diminution of pollution. Such a diminution of pollution can be realized by two manners.

The first happens when α is sufficiently low, and uses the fact that the emission ratio decreases with β whereas production increases. The second happens when α and k are high enough. Indeed, when α is sufficiently high, the R&D level provided is very high, so that to internalize a greater proportion of transboundary pollution while reducing pollution, it is preferable to increase the emission ratio (by reducing the R&D level) and to reduce production, in the case of a sufficiently high investment cost parameter k.

In some cases, pollution increases with the R&D spillover. Indeed, when α is neither too high nor too low and k is sufficiently high, production increases with β whereas the emission ratio decreases but not in a sufficiently amount because the innovation level and the investment cost parameter are very high, leading to an increase of pollution.

Since the R&D spillover is a free positive externality, the social welfare improves when it is increased. In the Appendix, we demonstrate this for almost all the cases concerning α and k, and we think there is no reason to get the opposite result for the remaining cases not considered.

6.Conclusion

This model captures the scale and technological effects and tries to answer the question of whether opening markets to international trade, in case of transboundary pollution, reduces pollution and increases social welfare. It also studies the role of the positive R&D spillover and the competition of firms on the common market in the internalization of the transfrontier negative externality.

We consider a non-cooperative and 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 in order to lower its emissions per-unit of production. This research activity is characterized by positive R&D spillovers.

In autarky, we show that without R&D spillovers ($\beta=0$), transboundary pollution is completely non-internalized. The higher R&D spillover is, the higher the proportion of transboundary pollution internalized is. Moreover, opening markets to international trade helps competing countries to better internalize transborder pollution through the competition of firms on the common market.

Consequently, when the R&D spillover increases, pollution decreases in most cases whereas the social welfare improves. Therefore, it is recommended for countries to voluntarily increase their positive R&D externality through scientific communications or exchanges. The issue of cooperation in R&D has not been examined in this paper, but we think that it would be beneficial for countries. In addition, if countries fully cooperate, then transboundary pollution is completely internalized and they reach the first best.

Opening markets to international trade leads to both more investment in R&D and more production. When α is sufficiently low, pollution in common market is lower than in autarky implying a greater social welfare. Nevertheless, when a and k are high enough, international trade increases pollution and therefore reduces the social welfare. Indeed, the non-internalized transborder pollution may be greater, even if opening markets enables to better internalize the transfrontier externality; moreover, the increase of production and innovation may decrease the profit of firms. Since this last situation happens under very restrictive conditions, we can say that, in general, opening markets to international trade reduces pollution and improves the social welfare.

Even if we came to our results by a simple but intuitive model, many of them could be generalized to a more complicated context. In this paper, we have assigned the same importance to consumer welfare and profit of the firm. A possible extension of this work is to give these latter different weights i.e. to suppose that there is positive cost of raising public funds. Another extension is to introduce asymmetric information between the regulators and their respective firms concerning their production costs or R&D activity. This may reinforce the potential gain to open markets to international trade because the competition on the common market may decrease the informational rents captured by firms.

Appendix

When we replace γ by α, conditions (C.1) to (C.8) become :

$$a-\theta>\frac{(1+2\beta)\alpha}{1+\beta}\quad \text{(C.1)},\quad k>\frac{1}{4}(1+\beta)(1+2\beta)\alpha^2\quad \text{(C.2)},\quad k>\frac{1}{4}(1+\beta)^2\alpha(a-\theta)\quad \text{(C.3)}$$

$$k>\frac{1}{16}(15\beta^2-10\beta+7)\alpha^2\quad \text{(C.4)},\quad a-\theta>\frac{(1+5\beta)\alpha}{2(1+\beta)}\quad \text{(C.5)},\quad k>\frac{1}{8}(1+\beta)(1+5\beta)\alpha^2\quad \text{(C.6)},$$

(C.7)=(C.3), $a-\theta>\alpha$ (C.8).

These conditions mean that α is sufficiently low and k is sufficiently high.

Using (7) and (14) for γ=α, the symmetric equilibrium values of R&D become :

$$x_i^a=\frac{\alpha\left[(1+\beta)(a-\theta)-(1+2\beta)\alpha\right]}{4k-(1+\beta)(1+2\beta)\alpha^2}\quad \text{and}\quad x_i^{cm}=\frac{\alpha\left[2(1+\beta)(a-\theta)-(1+5\beta)\alpha\right]}{8k-(1+\beta)(1+5\beta)\alpha^2}\qquad (16)$$

A)Proof of Proposition 1

From (16), we have :

$$x_i^{cm}-x_i^a=\frac{(1-\beta)\alpha^2\left[4k-(1+\beta)^2\alpha(a-\theta)\right]}{\left[8k-(1+\beta)(1+5\beta)\alpha^2\right]\left[4k-(1+\beta)(1+2\beta)\alpha^2\right]}$$

From (C.2), (C.3) and (C.6), we get $x_i^{cm}-x_i^a>0$, which implies that $e_i^{cm}<e_i^a$, and from (8) and (15), we also have $q_i^{cm}>q_i^a$.

B)Proof of Proposition 2

To compare the emission levels in autarky and common market, we rewrite the symmetric equilibrium pollution level of a firm as $E_i(x_i) = (1-(1+\beta)x_i)q_i(x_i)$,where $q_i(x_i)$ are given by (8) and (15). Thus, $\frac{dE_i(x_i)}{dx_i} = \frac{1}{2}(1+\beta)\left[-2(1+\beta)\alpha x_i + 2\alpha - (a-\theta)\right]$.

i) $\frac{dE_i(x_i)}{dx_i} < 0 \Leftrightarrow x_i > x^1 = \frac{2\alpha - (a-\theta)}{2(1+\beta)\alpha}$

The above inequality is verified by any $x_i > 0$ when (a-θ)>2α.

Therefore, if (a-θ)>2α, then $dE_i(x_i)/dx_i < 0 \quad \forall x_i > 0$, and since $x_i^{cm} > x_i^a$, this implies that $E_i^{cm} < E_i^a$.

ii) $\frac{dE_i(x_i)}{dx_i} > 0 \Leftrightarrow x_i < x^1$. Therefore, if (a-θ)<2α, we have $dE_i(x_i)/dx_i > 0 \quad \forall x_i < x^1$.

To compare E_i^{cm} and E_i^a, we need that $x_i^{cm} < x^1$.

$$x_i^{cm} - x^1 = \frac{8k\left[(a-\theta) - 2\alpha\right] + (1+\beta)(3-\beta)\alpha^2(a-\theta)}{2(1+\beta)\alpha\left[8k - (1+\beta)(1+5\beta)\alpha^2\right]} < 0 \Leftrightarrow k > k^1 = \frac{(1+\beta)(3-\beta)\alpha^2(a-\theta)}{8(2\alpha - (a-\theta))}$$

Therefore, if (a-θ)<2α and $k > k^1$, then $dE_i(x_i)/dx_i > 0 \quad \forall x_i < x^1$, implying that $E_i^{cm} > E_i^a$.

C)Proof of Proposition 3

By using expressions (2) and (9) for the symmetric case, the symmetric equilibrium social welfare of a country can be written as :

$$S_i(x_i) = -\left(q_i(x_i)\right)^2 - 2\alpha(1-(1+\beta)x_i)q_i(x_i) + (a-\theta)q_i(x_i) - kx_i^2$$

where q_i and x_i could be the equilibrium values in autarky or common market. By using expressions (8) and (15), we can show that :

$$\frac{dS_i(x_i)}{dx_i} = \left[\frac{3}{2}(1+\beta)^2\alpha^2 - 2k\right]x_i + (1+\beta)\alpha(a-\theta) - \frac{3}{2}(1+\beta)\alpha^2 \qquad (17)$$

•Suppose that $k < \frac{3}{4}(1+\beta)^2\alpha^2$

The above inequality is not in contradiction with (C.2), (C.3), (C.4), (C.6) and (C.7).

$$\frac{dS_i(x_i)}{dx_i} > 0 \Leftrightarrow x_i > x^2 = (1+\beta)\alpha\frac{2(a-\theta) - 3\alpha}{4k - 3(1+\beta)^2\alpha^2}$$

Therefore, if $(a-\theta)>\frac{3}{2}\alpha$ and $k<\frac{3}{4}(1+\beta)^2\alpha^2$, then $dS_i(x_i)/dx_i>0 \quad \forall x_i>0$, implying that $S_i^{cm}>S_i^a$.

•Suppose that $k>\frac{3}{4}(1+\beta)^2\alpha^2$, then $\frac{dS_i(x_i)}{dx_i}>0 \Leftrightarrow x_i<x^2$

If $(a-\theta)>\frac{3}{2}\alpha$, then $x^2>0$ and we need to have $x_i^{cm}<x^2$.

$$x_i^{cm}-x^2=\alpha\frac{4k[-2(1+\beta)(a-\theta)+(5+\beta)\alpha]-4(1+\beta)(1-\beta^2)\alpha^2(a-\theta)}{[8k-(1+\beta)(1+5\beta)\alpha^2][4k-3(1+\beta)^2\alpha^2]}$$

If $(a-\theta)>\frac{5+\beta}{2(1+\beta)}\alpha$, then $x_i^{cm}<x^2$.

Thus, if $(a-\theta)>\frac{5+\beta}{2(1+\beta)}\alpha$ and $k>\frac{3}{4}(1+\beta)^2\alpha^2$, then $dS_i(x_i)/dx_i>0 \quad \forall x_i<x^2$, implying that $S_i^{cm}>S_i^a$.

Since $\frac{5+\beta}{2(1+\beta)}\alpha>\frac{3}{2}\alpha$, then if $(a-\theta)>\frac{5+\beta}{2(1+\beta)}\alpha$, we have $dS_i(x_i)/dx_i>0$ on an open interval containing x_i^a and x_i^{cm}, implying that $S_i^{cm}>S_i^a$.

Lastly, $\frac{dS_i(x_i)}{dx_i}<0 \Leftrightarrow x_i>x^2$: true for any $x_i>0$ when $(a-\theta)<\frac{3}{2}\alpha$.

Therefore, if $(a-\theta)<\frac{3}{2}\alpha$ and $k>\frac{3}{4}(1+\beta)^2\alpha^2$, then $dS_i(x_i)/dx_i<0 \quad \forall x_i>0$, implying that $S_i^{cm}<S_i^a$.

D)Proof of Proposition 4

i)* The numerator of $\frac{1}{\alpha}\frac{dx_i^a(\beta)}{d\beta}$ is $4k[(a-\theta)-2\alpha]+\alpha^2[2(1+\beta)^2(a-\theta)-(1+2\beta)^2\alpha]$, whereas the denominator is positive. Because of condition (C.1), the term between the above second square brackets is positive. Thus :

•If (a-θ)>2α, then $dx_i^a(\beta)/d\beta>0$.

•If (a-θ)<2α, then $\frac{dx_i^a(\beta)}{d\beta}<0 \Leftrightarrow k>k^2=\frac{\alpha^2[2(1+\beta)^2(a-\theta)-(1+2\beta)^2\alpha]}{4[2\alpha-(a-\theta)]}$

The term $\frac{1}{\alpha}\frac{dx_i^{cm}(\beta)}{d\beta}$ has the same sign than its numerator $8k\left[2(a-\theta)-5\alpha\right]+\alpha^2\left[10(1+\beta)^2(a-\theta)-(1+5\beta)^2\alpha\right]$. Because of condition (C.5), the term between the second square brackets is positive. Thus :

•If $(a-\theta)>\frac{5}{2}\alpha$, then $dx_i^{cm}(\beta)/d\beta>0$.

•If $(a-\theta)<\frac{5}{2}\alpha$, then $\frac{dx_i^{cm}(\beta)}{d\beta}<0 \Leftrightarrow k>k^3=\frac{\alpha^2\left[10(1+\beta)^2(a-\theta)-(1+5\beta)^2\alpha\right]}{8\left[5\alpha-2(a-\theta)\right]}$

*We have $e_i(\beta)=\left[1-(1+\beta)x_i(\beta)\right]$ and $\frac{de_i(\beta)}{d\beta}=-x_i(\beta)-(1+\beta)\frac{dx_i(\beta)}{d\beta}$ (18)

The term $-\frac{1}{\alpha}\frac{de_i^{a}(\beta)}{d\beta}$ has the same sign than its numerator $4k\left[2(1+\beta)(a-\theta)-(3+4\beta)\alpha\right]+(1+\beta)^2\alpha^2(a-\theta)$. Therefore :

•If $(a-\theta)>\frac{(3+4\beta)\alpha}{2(1+\beta)}$, then $de_i^{a}(\beta)/d\beta<0$.

•If $(a-\theta)<\frac{(3+4\beta)\alpha}{2(1+\beta)}$ and k is high enough, then $de_i^{a}(\beta)/d\beta>0$.

The term $-\frac{1}{\alpha}\frac{de_i^{cm}(\beta)}{d\beta}$ has the same sign than its numerator $8k\left[4(1+\beta)(a-\theta)-2(3+5\beta)\alpha\right]+8(1+\beta)^2\alpha^2(a-\theta)$. Therefore :

•If $(a-\theta)>\frac{(3+5\beta)\alpha}{2(1+\beta)}$, then $de_i^{cm}(\beta)/d\beta<0$.

•If $(a-\theta)<\frac{(3+5\beta)\alpha}{2(1+\beta)}$ and k is high enough, then $de_i^{cm}(\beta)/d\beta>0$.

*From expressions (8), (15) and (18) we deduce $q_i(\beta)=q_i(\beta,x_i(\beta))\Rightarrow$

$$\frac{dq_i(\beta)}{d\beta}=\frac{\partial q_i}{\partial\beta}+\frac{dx_i(\beta)}{d\beta}\frac{\partial q_i}{\partial x_i}=-\frac{\alpha}{2}\frac{de_i(\beta)}{d\beta} \quad (19)$$

Thus, the quantity produced and the emission ratio vary in opposite directions with respect to the R&D spillover.

ii)We have $E_i(\beta)=e_i(\beta)q_i(\beta)$ and $\frac{dE_i(\beta)}{d\beta}=\frac{de_i(\beta)}{d\beta}q_i(\beta)+e_i(\beta)\frac{dq_i(\beta)}{d\beta}$

Using (19), (8) and (15), we establish that :

$$\frac{dE_i(\mathbf{b})}{d\mathbf{b}} = \frac{1}{\mathbf{a}}\frac{dq_i(\mathbf{b})}{d\mathbf{b}}\left[2\mathbf{a} - (a-\mathbf{q}) - 2(1+\mathbf{b})\mathbf{a}x_i(\mathbf{b})\right] = \frac{1}{\mathbf{a}}\frac{dq_i(\mathbf{b})}{d\mathbf{b}} f_i(\mathbf{b}) \qquad (20)$$

•If (a-θ)>2α, then $dq_i(\mathbf{b})/d\mathbf{b} > 0$ implying that $dE_i(\mathbf{b})/d\mathbf{b} < 0$.

•Using the expression of $x_i^a(\mathbf{b})$, $f_i^a(\mathbf{b})$ has the sign of its numerator $4k\left[2\mathbf{a} - (a-\mathbf{q})\right] - (1+\mathbf{b})\mathbf{a}^2(a-\mathbf{q})$. Therefore :

If $(a-\mathbf{q}) < \frac{(3+4\mathbf{b})\mathbf{a}}{2(1+\mathbf{b})}$ and k is high enough, then $dq_i^a(\mathbf{b})/d\mathbf{b} < 0$ implying that $dE_i^a(\mathbf{b})/d\mathbf{b} < 0$.

If $\frac{(3+4\mathbf{b})\mathbf{a}}{2(1+\mathbf{b})} < a - \mathbf{q} < 2\mathbf{a}$ and k is high enough, then $dq_i^a(\mathbf{b})/d\mathbf{b} > 0$ implying that $dE_i^a(\mathbf{b})/d\mathbf{b} > 0$.

•Using the expression of $x_i^{cm}(\mathbf{b})$, $f_i^{cm}(\mathbf{b})$ has the sign of its numerator $8k\left[2\mathbf{a} - (a-\mathbf{q})\right] - (3-\mathbf{b})(1+\mathbf{b})\mathbf{a}^2(a-\mathbf{q})$. Therefore :

If $(a-\mathbf{q}) < \frac{(3+5\mathbf{b})\mathbf{a}}{2(1+\mathbf{b})}$ and k is high enough, then $dq_i^{cm}(\mathbf{b})/d\mathbf{b} < 0$ implying that $dE_i^{cm}(\mathbf{b})/d\mathbf{b} < 0$.

If $\frac{(3+5\mathbf{b})\mathbf{a}}{2(1+\mathbf{b})} < a - \mathbf{q} < 2\mathbf{a}$ and k is high enough, then $dq_i^{cm}(\mathbf{b})/d\mathbf{b} > 0$ implying that $dE_i^{cm}(\mathbf{b})/d\mathbf{b} > 0$.

iii) Using expressions (2) and (9), the symmetric equilibrium social welfare of a country can be written as :

$$S_i(\mathbf{b}) = -(q_i(\mathbf{b}))^2 - 2\mathbf{a}E_i(\mathbf{b}) + (a-\mathbf{q})q_i(\mathbf{b}) - k(x_i(\mathbf{b}))^2$$

Deriving with respect to β and then using expressions (8), (15) and (20), we get :

$$\frac{dS_i(\mathbf{b})}{d\mathbf{b}} = \frac{dq_i(\mathbf{b})}{d\mathbf{b}} g_i(\mathbf{b}) - 2kx_i(\mathbf{b})\frac{dx_i(\mathbf{b})}{d\mathbf{b}} \qquad (21)$$

where $g_i(\mathbf{b}) = 3(1+\mathbf{b})\mathbf{a}x_i(\mathbf{b}) + 2(a-\mathbf{q}) - 3\mathbf{a}$.

The previous results on the variations of $q_i(\mathbf{b})$ and $x_i(\mathbf{b})$ with respect to β, show that :

•If $\frac{(3+4\mathbf{b})\mathbf{a}}{2(1+\mathbf{b})} < a - \mathbf{q} < 2\mathbf{a}$ and k is high enough, then $dS_i^a(\mathbf{b})/d\mathbf{b} > 0$.

•If $\frac{(3+5\boldsymbol{b})\boldsymbol{a}}{2(1+\boldsymbol{b})} < a - \boldsymbol{q} < \frac{5}{2}\boldsymbol{a}$ and k is high enough, then $dS_i^{cm}(\boldsymbol{b})/d\boldsymbol{b} > 0$.

•Using the expression of $x_i^a(\boldsymbol{b})$, $g_i^a(\boldsymbol{b})$ has the sign of its numerator $4k\left[2(a-\boldsymbol{q})-3\boldsymbol{a}\right]+(1-\boldsymbol{b}^2)\boldsymbol{a}^2(a-\boldsymbol{q})$.

Thus, if $(a-\boldsymbol{q}) < \frac{3}{2}\boldsymbol{a}$ and k is high enough, then $dS_i^a(\boldsymbol{b})/d\boldsymbol{b} > 0$.

•Using the expression of $x_i^{cm}(\boldsymbol{b})$, $g_i^{cm}(\boldsymbol{b})$ has the sign of its numerator $8k\left[2(a-\boldsymbol{q})-3\boldsymbol{a}\right]+4(1-\boldsymbol{b}^2)\boldsymbol{a}^2(a-\boldsymbol{q})$.

Thus, if $(a-\boldsymbol{q}) < \frac{3}{2}\boldsymbol{a}$ and k is high enough, then $dS_i^{cm}(\boldsymbol{b})/d\boldsymbol{b} > 0$.

•Using expressions (18) and (19), (21) becomes :

$$\frac{dS_i(\boldsymbol{b})}{d\boldsymbol{b}} = \frac{\boldsymbol{a}}{2}\left[x_i(\boldsymbol{b}) + (1+\boldsymbol{b})\frac{dx_i(\boldsymbol{b})}{d\boldsymbol{b}}\right]\left[3(1+\boldsymbol{b})\boldsymbol{a}x_i(\boldsymbol{b}) + 2(a-\boldsymbol{q}) - 3\boldsymbol{a}\right] - 2kx_i(\boldsymbol{b})\frac{dx_i(\boldsymbol{b})}{d\boldsymbol{b}}$$

Using the equality (17), we get :

$$\frac{dS_i(\boldsymbol{b})}{d\boldsymbol{b}} = \frac{\boldsymbol{a}}{2}x_i(\boldsymbol{b})\left[3(1+\boldsymbol{b})\boldsymbol{a}x_i(\boldsymbol{b}) + 2(a-\boldsymbol{q}) - 3\boldsymbol{a}\right] + \frac{dx_i(\boldsymbol{b})}{d\boldsymbol{b}}\frac{dS_i(x_i(\boldsymbol{b}))}{d(x_i(\boldsymbol{b}))}$$

The previous results on $\frac{dx_i(\boldsymbol{b})}{d\boldsymbol{b}}$ and $\frac{dS_i(x_i)}{dx_i}$, imply that if $(a-\boldsymbol{q}) > \frac{5}{2}\boldsymbol{a}$, then $\frac{dS_i(\boldsymbol{b})}{d\boldsymbol{b}} > 0$.

References

Antweiler, W., B.R Copeland and M.S. Taylor, 2001, ''Is Free Trade Good for the Environment'', The American Economic Review, 91, 877-908.

D'Aspremont, C. and A. Jacquemin, 1988, ''Cooperative and Noncooperative R&D in Duopoly with Spillovers'', The American Economic Review, 78, 1133-1137.

Bac, M, 1996, ''Incomplete Information and Incentives to Free Ride on International Environmental Resources'', Journal of Environmental Economics and Management, 30, 301-315.

Copeland, B.R. and M.S. Taylor, 1994, ''North-South Trade and the Environment'', Quarterly Journal of Economics, 109, 755-787.

Copeland, B.R. and M.S. Taylor, 1995, ''Trade and Transboundary Pollution'', The American Economic Review, 85, 716-737.

Fernandez, L, 2002, ''Trade's Dynamic Solutions to Transboundary Pollution'', Journal of Environmental Economics and Management, 43, 386-411.

Hoel, M, 1997, ''Coordination of Environmental Policy for Transboundary Environmental Problems ?'', Journal of Public Economics, 66, 199-224.

Mansouri, F. and S. Ben Youssef, 2000, ''Regulation and Coordination of International Environmental Externalities with Incomplete Information and Costly Public Funds'', Journal of Public Economic Theory, 2, 365-388.

Péchoux, I. and J. Pouyet, 2003, ''Regulated Firms with Transboundary Pollution :Does International Competition Improve Efficiency ?'', Journal of Public Economic Theory, 5, 499-525.

Petrakis, E. and A. Xepapadeas, 1996, ''Environmental Consciousness and Moral Hazard in International Agreements to Protect the Environment'', Journal of Public Economics, 60, 95-110.

Reppelin-Hill, V, 1999, ''Trade and Environment :An Empirical Analysis of the Technology Effect in the Steel Industry'', Journal of Environmental Economics and Management, 38, 283-301.

Santore, R., H.D. Robison and Y. Klein, 2001, ''Strategic State-Level Environmental Policy with Asymmetric Pollution Spillovers'', Journal of Public Economics, 80, 199-224.

Zagonari, F, 1998, ''International Pollution Problems : Unilateral Initiatives by Environmental Groups in One Country'', Journal of Environmental Economics and Management, 36, 46-69.

NOTE DI LAVORO DELLA FONDAZIONE ENI ENRICO MATTEI
Fondazione Eni Enrico Mattei Working Paper Series
Our working papers are available on the Internet at the following addresses:
http://www.feem.it/web/activ/_wp.html
http://papers.ssrn.com

SUST	1.2002	*K. TANO, M.D. FAMINOW, M. KAMUANGA and B. SWALLOW*: Using Conjoint Analysis to Estimate Farmers' Preferences for Cattle Traits in West Africa
ETA	2.2002	*Efrem CASTELNUOVO and Paolo SURICO*: What Does Monetary Policy Reveal about Central Bank's Preferences?
WAT	3.2002	*Duncan KNOWLER and Edward BARBIER*: The Economics of a "Mixed Blessing" Effect: A Case Study of the Black Sea
CLIM	4.2002	*Andreas LÖSCHEL*: Technological Change in Economic Models of Environmental Policy: A Survey
VOL	5.2002	*Carlo CARRARO and Carmen MARCHIORI*: Stable Coalitions
CLIM	6.2002	*Marzio GALEOTTI, Alessandro LANZA and Matteo MANERA*: Rockets and Feathers Revisited: An International Comparison on European Gasoline Markets
ETA	7.2002	*Effrosyni DIAMANTOUDI and Eftichios S. SARTZETAKIS*: Stable International Environmental Agreements: An Analytical Approach
KNOW	8.2002	*Alain DESDOIGTS*: Neoclassical Convergence Versus Technological Catch-up: A Contribution for Reaching a Consensus
NRM	9.2002	*Giuseppe DI VITA:* Renewable Resources and Waste Recycling
KNOW	10.2002	*Giorgio BRUNELLO*: Is Training More Frequent when Wage Compression is Higher? Evidence from 11 European Countries
ETA	11.2002	*Mordecai KURZ, Hehui JIN and Maurizio MOTOLESE*: Endogenous Fluctuations and the Role of Monetary Policy
KNOW	12.2002	*Reyer GERLAGH and Marjan W. HOFKES:* Escaping Lock-in: The Scope for a Transition towards Sustainable Growth?
NRM	13.2002	*Michele MORETTO and Paolo ROSATO*: The Use of Common Property Resources: A Dynamic Model
CLIM	14.2002	*Philippe QUIRION*: Macroeconomic Effects of an Energy Saving Policy in the Public Sector
CLIM	15.2002	*Roberto ROSON*: Dynamic and Distributional Effects of Environmental Revenue Recycling Schemes: Simulations with a General Equilibrium Model of the Italian Economy
CLIM	16.2002	*Francesco RICCI* (l): Environmental Policy Growth when Inputs are Differentiated in Pollution Intensity
ETA	17.2002	*Alberto PETRUCCI*: Devaluation (Levels versus Rates) and Balance of Payments in a Cash-in-Advance Economy
Coalition Theory Network	18.2002	*László Á. KÓCZY* (liv*):* The Core in the Presence of Externalities
Coalition Theory Network	19.2002	*Steven J. BRAMS, Michael A. JONES and D. Marc KILGOUR* (liv): Single-Peakedness and Disconnected Coalitions
Coalition Theory Network	20.2002	*Guillaume HAERINGER* (liv): On the Stability of Cooperation Structures
NRM	21.2002	*Fausto CAVALLARO and Luigi CIRAOLO:* Economic and Environmental Sustainability: A Dynamic Approach in Insular Systems
CLIM	22.2002	*Barbara BUCHNER, Carlo CARRARO, Igor CERSOSIMO and Carmen MARCHIORI*: Back to Kyoto? US Participation and the Linkage between R&D and Climate Cooperation
CLIM	23.2002	*Andreas LÖSCHEL and ZhongXIANG ZHANG:* The Economic and Environmental Implications of the US Repudiation of the Kyoto Protocol and the Subsequent Deals in Bonn and Marrakech
ETA	24.2002	*Marzio GALEOTTI, Louis J. MACCINI and Fabio SCHIANTARELLI*: Inventories, Employment and Hours
CLIM	25.2002	*Hannes EGLI:* Are Cross-Country Studies of the Environmental Kuznets Curve Misleading? New Evidence from Time Series Data for Germany
ETA	26.2002	*Adam B. JAFFE, Richard G. NEWELL and Robert N. STAVINS*: Environmental Policy and Technological Change
SUST	27.2002	*Joseph C. COOPER and Giovanni SIGNORELLO*: Farmer Premiums for the Voluntary Adoption of Conservation Plans
SUST	28.2002	*The ANSEA Network*: Towards An Analytical Strategic Environmental Assessment
KNOW	29.2002	*Paolo SURICO*: Geographic Concentration and Increasing Returns: a Survey of Evidence
ETA	30.2002	*Robert N. STAVINS:* Lessons from the American Experiment with Market-Based Environmental Policies

NRM	31.2002	*Carlo GIUPPONI and Paolo ROSATO:* Multi-Criteria Analysis and Decision-Support for Water Management at the Catchment Scale: An Application to Diffuse Pollution Control in the Venice Lagoon
NRM	32.2002	*Robert N. STAVINS*: National Environmental Policy During the Clinton Years
KNOW	33.2002	*A. SOUBEYRAN and H. STAHN* : Do Investments in Specialized Knowledge Lead to Composite Good Industries?
KNOW	34.2002	*G. BRUNELLO, M.L. PARISI and Daniela SONEDDA:* Labor Taxes, Wage Setting and the Relative Wage Effect
CLIM	35.2002	*C. BOEMARE and P. QUIRION* (lv): Implementing Greenhouse Gas Trading in Europe: Lessons from Economic Theory and International Experiences
CLIM	36.2002	*T.TIETENBERG* (lv): The Tradable Permits Approach to Protecting the Commons: What Have We Learned?
CLIM	37.2002	*K. REHDANZ and R.J.S. TOL* (lv): On National and International Trade in Greenhouse Gas Emission Permits
CLIM	38.2002	*C. FISCHER* (lv): Multinational Taxation and International Emissions Trading
SUST	39.2002	*G. SIGNORELLO and G. PAPPALARDO:* Farm Animal Biodiversity Conservation Activities in Europe under the Framework of Agenda 2000
NRM	40.2002	*S .M. CAVANAGH, W. M. HANEMANN and R. N. STAVINS:* Muffled Price Signals: Household Water Demand under Increasing-Block Prices
NRM	41.2002	*A. J. PLANTINGA, R. N. LUBOWSKI and R. N. STAVINS:* The Effects of Potential Land Development on Agricultural Land Prices
CLIM	42.2002	*C. OHL* (lvi): Inducing Environmental Co-operation by the Design of Emission Permits
CLIM	43.2002	*J. EYCKMANS, D. VAN REGEMORTER and V. VAN STEENBERGHE* (lvi): Is Kyoto Fatally Flawed? An Analysis with MacGEM
CLIM	44.2002	*A. ANTOCI and S. BORGHESI* (lvi): Working Too Much in a Polluted World: A North-South Evolutionary Model
ETA	45.2002	*P. G. FREDRIKSSON, Johan A. LIST and Daniel MILLIMET* (lvi): Chasing the Smokestack: Strategic Policymaking with Multiple Instruments
ETA	46.2002	*Z. YU* (lvi): A Theory of Strategic Vertical DFI and the Missing Pollution-Haven Effect
SUST	47.2002	*Y. H. FARZIN*: Can an Exhaustible Resource Economy Be Sustainable?
SUST	48.2002	*Y. H. FARZIN*: Sustainability and Hamiltonian Value
KNOW	49.2002	*C. PIGA and M. VIVARELLI*: Cooperation in R&D and Sample Selection
Coalition Theory Network	50.2002	*M. SERTEL and A. SLINKO* (liv): Ranking Committees, Words or Multisets
Coalition Theory Network	51.2002	*Sergio CURRARINI* (liv): Stable Organizations with Externalities
ETA	52.2002	*Robert N. STAVINS*: Experience with Market-Based Policy Instruments
ETA	53.2002	*C.C. JAEGER, M. LEIMBACH, C. CARRARO, K. HASSELMANN, J.C. HOURCADE, A. KEELER and R. KLEIN* (liii): Integrated Assessment Modeling: Modules for Cooperation
CLIM	54.2002	*Scott BARRETT* (liii)*:* Towards a Better Climate Treaty
ETA	55.2002	*Richard G. NEWELL and Robert N. STAVINS*: Cost Heterogeneity and the Potential Savings from Market-Based Policies
SUST	56.2002	*Paolo ROSATO and Edi DEFRANCESCO*: Individual Travel Cost Method and Flow Fixed Costs
SUST	57.2002	*Vladimir KOTOV and Elena NIKITINA* (lvii): Reorganisation of Environmental Policy in Russia: The Decade of Success and Failures in Implementation of Perspective Quests
SUST	58.2002	*Vladimir KOTOV* (lvii): Policy in Transition: New Framework for Russia's Climate Policy
SUST	59.2002	*Fanny MISSFELDT and Arturo VILLAVICENCO* (lvii): How Can Economies in Transition Pursue Emissions Trading or Joint Implementation?
VOL	60.2002	*Giovanni DI BARTOLOMEO, Jacob ENGWERDA, Joseph PLASMANS and Bas VAN AARLE:* Staying Together or Breaking Apart: Policy-Makers' Endogenous Coalitions Formation in the European Economic and Monetary Union
ETA	61.2002	*Robert N. STAVINS, Alexander F.WAGNER and Gernot WAGNER*: Interpreting Sustainability in Economic Terms: Dynamic Efficiency Plus Intergenerational Equity
PRIV	62.2002	*Carlo CAPUANO*: Demand Growth, Entry and Collusion Sustainability
PRIV	63.2002	*Federico MUNARI and Raffaele ORIANI*: Privatization and R&D Performance: An Empirical Analysis Based on Tobin's Q
PRIV	64.2002	*Federico MUNARI and Maurizio SOBRERO*: The Effects of Privatization on R&D Investments and Patent Productivity
SUST	65.2002	*Orley ASHENFELTER and Michael GREENSTONE*: Using Mandated Speed Limits to Measure the Value of a Statistical Life
ETA	66.2002	*Paolo SURICO:* US Monetary Policy Rules: the Case for Asymmetric Preferences
PRIV	67.2002	*Rinaldo BRAU and Massimo FLORIO*: Privatisations as Price Reforms: Evaluating Consumers' Welfare Changes in the U.K.
CLIM	68.2002	*Barbara K. BUCHNER and Roberto ROSON*: Conflicting Perspectives in Trade and Environmental Negotiations
CLIM	69.2002	*Philippe QUIRION*: Complying with the Kyoto Protocol under Uncertainty: Taxes or Tradable Permits?
SUST	70.2002	*Anna ALBERINI, Patrizia RIGANTI and Alberto LONGO*: Can People Value the Aesthetic and Use Services of Urban Sites? Evidence from a Survey of Belfast Residents
SUST	71.2002	*Marco PERCOCO:* Discounting Environmental Effects in Project Appraisal

NRM	72.2002	*Philippe BONTEMS and Pascal FAVARD*: Input Use and Capacity Constraint under Uncertainty: The Case of Irrigation
PRIV	73.2002	*Mohammed OMRAN:* The Performance of State-Owned Enterprises and Newly Privatized Firms: Empirical Evidence from Egypt
PRIV	74.2002	*Mike BURKART, Fausto PANUNZI and Andrei SHLEIFER:* Family Firms
PRIV	75.2002	*Emmanuelle AURIOL, Pierre M. PICARD:* Privatizations in Developing Countries and the Government Budget Constraint
PRIV	76.2002	*Nichole M. CASTATER*: Privatization as a Means to Societal Transformation: An Empirical Study of Privatization in Central and Eastern Europe and the Former Soviet Union
PRIV	77.2002	*Christoph LÜLSFESMANN*: Benevolent Government, Managerial Incentives, and the Virtues of Privatization
PRIV	78.2002	*Kate BISHOP, Igor FILATOTCHEV and Tomasz MICKIEWICZ*: Endogenous Ownership Structure: Factors Affecting the Post-Privatisation Equity in Largest Hungarian Firms
PRIV	79.2002	*Theodora WELCH and Rick MOLZ*: How Does Trade Sale Privatization Work? Evidence from the Fixed-Line Telecommunications Sector in Developing Economies
PRIV	80.2002	*Alberto R. PETRUCCI*: Government Debt, Agent Heterogeneity and Wealth Displacement in a Small Open Economy
CLIM	81.2002	*Timothy SWANSON and Robin MASON* (lvi): The Impact of International Environmental Agreements: The Case of the Montreal Protocol
PRIV	82.2002	*George R.G. CLARKE and Lixin Colin XU:* Privatization, Competition and Corruption: How Characteristics of Bribe Takers and Payers Affect Bribe Payments to Utilities
PRIV	83.2002	*Massimo FLORIO and Katiuscia MANZONI*: The Abnormal Returns of UK Privatisations: From Underpricing to Outperformance
NRM	84.2002	*Nelson LOURENÇO, Carlos RUSSO MACHADO, Maria do ROSÁRIO JORGE and Luís RODRIGUES*: An Integrated Approach to Understand Territory Dynamics. The Coastal Alentejo (Portugal)
CLIM	85.2002	*Peter ZAPFEL and Matti VAINIO* (lv): Pathways to European Greenhouse Gas Emissions Trading History and Misconceptions
CLIM	86.2002	*Pierre COURTOIS*: Influence Processes in Climate Change Negotiations: Modelling the Rounds
ETA	87.2002	*Vito FRAGNELLI and Maria Erminia MARINA* (lviii): Environmental Pollution Risk and Insurance
ETA	88.2002	*Laurent FRANCKX* (lviii): Environmental Enforcement with Endogenous Ambient Monitoring
ETA	89.2002	*Timo GOESCHL and Timothy M. SWANSON* (lviii): Lost Horizons. The noncooperative management of an evolutionary biological system.
ETA	90.2002	*Hans KEIDING* (lviii): Environmental Effects of Consumption: An Approach Using DEA and Cost Sharing
ETA	91.2002	*Wietze LISE* (lviii): A Game Model of People's Participation in Forest Management in Northern India
CLIM	92.2002	*Jens HORBACH*: Structural Change and Environmental Kuznets Curves
ETA	93.2002	*Martin P. GROSSKOPF:* Towards a More Appropriate Method for Determining the Optimal Scale of Production Units
VOL	94.2002	*Scott BARRETT and Robert STAVINS*: Increasing Participation and Compliance in International Climate Change Agreements
CLIM	95.2002	*Banu BAYRAMOGLU LISE and Wietze LISE:* Climate Change, Environmental NGOs and Public Awareness in the Netherlands: Perceptions and Reality
CLIM	96.2002	*Matthieu GLACHANT*: The Political Economy of Emission Tax Design in Environmental Policy
KNOW	97.2002	*Kenn ARIGA and Giorgio BRUNELLO*: Are the More Educated Receiving More Training? Evidence from Thailand
ETA	98.2002	*Gianfranco FORTE and Matteo MANERA*: Forecasting Volatility in European Stock Markets with Non-linear GARCH Models
ETA	99.2002	*Geoffrey HEAL*: Bundling Biodiversity
ETA	100.2002	*Geoffrey HEAL, Brian WALKER, Simon LEVIN, Kenneth ARROW, Partha DASGUPTA, Gretchen DAILY, Paul EHRLICH, Karl-Goran MALER, Nils KAUTSKY, Jane LUBCHENCO, Steve SCHNEIDER and David STARRETT*: Genetic Diversity and Interdependent Crop Choices in Agriculture
ETA	101.2002	*Geoffrey HEAL:* Biodiversity and Globalization
VOL	102.2002	*Andreas LANGE*: Heterogeneous International Agreements – If per capita emission levels matter
ETA	103.2002	*Pierre-André JOUVET and Walid OUESLATI*: Tax Reform and Public Spending Trade-offs in an Endogenous Growth Model with Environmental Externality
ETA	104.2002	*Anna BOTTASSO and Alessandro SEMBENELLI*: Does Ownership Affect Firms' Efficiency? Panel Data Evidence on Italy
PRIV	105.2002	*Bernardo BORTOLOTTI, Frank DE JONG, Giovanna NICODANO and Ibolya SCHINDELE*: Privatization and Stock Market Liquidity
ETA	106.2002	*Haruo IMAI and Mayumi HORIE* (lviii): Pre-Negotiation for an International Emission Reduction Game
PRIV	107.2002	*Sudeshna GHOSH BANERJEE and Michael C. MUNGER*: Move to Markets? An Empirical Analysis of Privatisation in Developing Countries
PRIV	108.2002	*Guillaume GIRMENS and Michel GUILLARD*: Privatization and Investment: Crowding-Out Effect vs Financial Diversification
PRIV	109.2002	*Alberto CHONG and Florencio LÓPEZ-DE-SILANES*: Privatization and Labor Force Restructuring Around the World
PRIV	110.2002	*Nandini GUPTA*: Partial Privatization and Firm Performance
PRIV	111.2002	*François DEGEORGE, Dirk JENTER, Alberto MOEL and Peter TUFANO*: Selling Company Shares to Reluctant Employees: France Telecom's Experience

PRIV	112.2002	*Isaac OTCHERE*: Intra-Industry Effects of Privatization Announcements: Evidence from Developed and Developing Countries
PRIV	113.2002	*Yannis KATSOULAKOS and Elissavet LIKOYANNI*: Fiscal and Other Macroeconomic Effects of Privatization
PRIV	114.2002	*Guillaume GIRMENS:* Privatization, International Asset Trade and Financial Markets
PRIV	115.2002	*D. Teja FLOTHO:* A Note on Consumption Correlations and European Financial Integration
PRIV	116.2002	*Ibolya SCHINDELE and Enrico C. PEROTTI*: Pricing Initial Public Offerings in Premature Capital Markets: The Case of Hungary
PRIV	1.2003	*Gabriella CHIESA and Giovanna NICODANO*: Privatization and Financial Market Development: Theoretical Issues
PRIV	2.2003	*Ibolya SCHINDELE*: Theory of Privatization in Eastern Europe: Literature Review
PRIV	3.2003	*Wietze LISE, Claudia KEMFERT and Richard S.J. TOL*: Strategic Action in the Liberalised German Electricity Market
CLIM	4.2003	*Laura MARSILIANI and Thomas I. RENSTRÖM*: Environmental Policy and Capital Movements: The Role of Government Commitment
KNOW	5.2003	*Reyer GERLAGH*: Induced Technological Change under Technological Competition
ETA	6.2003	*Efrem CASTELNUOVO*: Squeezing the Interest Rate Smoothing Weight with a Hybrid Expectations Model
SIEV	7.2003	*Anna ALBERINI, Alberto LONGO, Stefania TONIN, Francesco TROMBETTA and Margherita TURVANI:* The Role of Liability, Regulation and Economic Incentives in Brownfield Remediation and Redevelopment: Evidence from Surveys of Developers
NRM	8.2003	*Elissaios PAPYRAKIS and Reyer GERLAGH*: Natural Resources: A Blessing or a Curse?
CLIM	9.2003	*A. CAPARRÓS, J.-C. PEREAU and T. TAZDAÏT*: North-South Climate Change Negotiations: a Sequential Game with Asymmetric Information
KNOW	10.2003	*Giorgio BRUNELLO and Daniele CHECCHI*: School Quality and Family Background in Italy
CLIM	11.2003	*Efrem CASTELNUOVO and Marzio GALEOTTI*: Learning By Doing vs Learning By Researching in a Model of Climate Change Policy Analysis
KNOW	12.2003	*Carole MAIGNAN, Gianmarco OTTAVIANO and Dino PINELLI (eds.)*: Economic Growth, Innovation, Cultural Diversity: What are we all talking about? A critical survey of the state-of-the-art
KNOW	13.2003	*Carole MAIGNAN, Gianmarco OTTAVIANO, Dino PINELLI and Francesco RULLANI* (lvix): Bio-Ecological Diversity vs. Socio-Economic Diversity. A Comparison of Existing Measures
KNOW	14.2003	*Maddy JANSSENS and Chris STEYAERT* (lvix): Theories of Diversity within Organisation Studies: Debates and Future Trajectories
KNOW	15.2003	*Tuzin BAYCAN LEVENT, Enno MASUREL and Peter NIJKAMP* (lvix): Diversity in Entrepreneurship: Ethnic and Female Roles in Urban Economic Life
KNOW	16.2003	*Alexandra BITUSIKOVA* (lvix): Post-Communist City on its Way from Grey to Colourful: The Case Study from Slovakia
KNOW	17.2003	*Billy E. VAUGHN and Katarina MLEKOV* (lvix): A Stage Model of Developing an Inclusive Community
KNOW	18.2003	*Selma van LONDEN and Arie de RUIJTER* (lvix): Managing Diversity in a Glocalizing World
Coalition Theory Network	19.2003	*Sergio CURRARINI:* On the Stability of Hierarchies in Games with Externalities
PRIV	20.2003	*Giacomo CALZOLARI and Alessandro PAVAN* (lvx): Monopoly with Resale
PRIV	21.2003	*Claudio MEZZETTI* (lvx): Auction Design with Interdependent Valuations: The Generalized Revelation Principle, Efficiency, Full Surplus Extraction and Information Acquisition
PRIV	22.2003	*Marco LiCalzi and Alessandro PAVAN* (lvx): Tilting the Supply Schedule to Enhance Competition in Uniform-Price Auctions
PRIV	23.2003	*David ETTINGER* (lvx): Bidding among Friends and Enemies
PRIV	24.2003	*Hannu VARTIAINEN* (lvx): Auction Design without Commitment
PRIV	25.2003	*Matti KELOHARJU, Kjell G. NYBORG and Kristian RYDQVIST* (lvx): Strategic Behavior and Underpricing in Uniform Price Auctions: Evidence from Finnish Treasury Auctions
PRIV	26.2003	*Christine A. PARLOUR and Uday RAJAN* (lvx): Rationing in IPOs
PRIV	27.2003	*Kjell G. NYBORG and Ilya A. STREBULAEV* (lvx): Multiple Unit Auctions and Short Squeezes
PRIV	28.2003	*Anders LUNANDER and Jan-Eric NILSSON* (lvx): Taking the Lab to the Field: Experimental Tests of Alternative Mechanisms to Procure Multiple Contracts
PRIV	29.2003	*TangaMcDANIEL and Karsten NEUHOFF* (lvx): Use of Long-term Auctions for Network Investment
PRIV	30.2003	*Emiel MAASLAND and Sander ONDERSTAL* (lvx): Auctions with Financial Externalities
ETA	31.2003	*Michael FINUS and Bianca RUNDSHAGEN:* A Non-cooperative Foundation of Core-Stability in Positive Externality NTU-Coalition Games
KNOW	32.2003	*Michele MORETTO*: Competition and Irreversible Investments under Uncertainty
PRIV	33.2003	*Philippe QUIRION:* Relative Quotas: Correct Answer to Uncertainty or Case of Regulatory Capture?
KNOW	34.2003	*Giuseppe MEDA, Claudio PIGA and Donald SIEGEL*: On the Relationship between R&D and Productivity: A Treatment Effect Analysis
ETA	35.2003	*Alessandra DEL BOCA, Marzio GALEOTTI and Paola ROTA:* Non-convexities in the Adjustment of Different Capital Inputs: A Firm-level Investigation

GG	36.2003	*Matthieu GLACHANT*: Voluntary Agreements under Endogenous Legislative Threats
PRIV	37.2003	*Narjess BOUBAKRI, Jean-Claude COSSET and Omrane GUEDHAMI*: Postprivatization Corporate Governance: the Role of Ownership Structure and Investor Protection
CLIM	38.2003	*Rolf GOLOMBEK and Michael HOEL*: Climate Policy under Technology Spillovers
KNOW	39.2003	*Slim BEN YOUSSEF*: Transboundary Pollution, R&D Spillovers and International Trade

(l) This paper was presented at the Workshop "Growth, Environmental Policies and Sustainability" organised by the Fondazione Eni Enrico Mattei, Venice, June 1, 2001
(li) This paper was presented at the Fourth Toulouse Conference on Environment and Resource Economics on "Property Rights, Institutions and Management of Environmental and Natural Resources", organised by Fondazione Eni Enrico Mattei, IDEI and INRA and sponsored by MATE, Toulouse, May 3-4, 2001
(lii) This paper was presented at the International Conference on "Economic Valuation of Environmental Goods", organised by Fondazione Eni Enrico Mattei in cooperation with CORILA, Venice, May 11, 2001
(liii) This paper was circulated at the International Conference on "Climate Policy – Do We Need a New Approach?", jointly organised by Fondazione Eni Enrico Mattei, Stanford University and Venice International University, Isola di San Servolo, Venice, September 6-8, 2001
(liv) This paper was presented at the Seventh Meeting of the Coalition Theory Network organised by the Fondazione Eni Enrico Mattei and the CORE, Université Catholique de Louvain, Venice, Italy, January 11-12, 2002
(lv) This paper was presented at the First Workshop of the Concerted Action on Tradable Emission Permits (CATEP) organised by the Fondazione Eni Enrico Mattei, Venice, Italy, December 3-4, 2001
(lvi) This paper was presented at the ESF EURESCO Conference on Environmental Policy in a Global Economy "The International Dimension of Environmental Policy", organised with the collaboration of the Fondazione Eni Enrico Mattei , Acquafredda di Maratea, October 6-11, 2001
(lvii) This paper was presented at the First Workshop of "CFEWE – Carbon Flows between Eastern and Western Europe", organised by the Fondazione Eni Enrico Mattei and Zentrum fur Europaische Integrationsforschung (ZEI), Milan, July 5-6, 2001
(lviii) This paper was presented at the Workshop on "Game Practice and the Environment", jointly organised by Università del Piemonte Orientale and Fondazione Eni Enrico Mattei, Alessandria, April 12-13, 2002
(lvix) This paper was presented at the ENGIME Workshop on "Mapping Diversity", Leuven, May 16-17, 2002
(lvx) 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

2002 SERIES

CLIM	*Climate Change Modelling and Policy* (Editor: Marzio Galeotti)
VOL	*Voluntary and International Agreements* (Editor: Carlo Carraro)
SUST	*Sustainability Indicators and Environmental Valuation* (Editor: Carlo Carraro)
NRM	*Natural Resources Management* (Editor: Carlo Giupponi)
KNOW	*Knowledge, Technology, Human Capital* (Editor: Dino Pinelli)
MGMT	*Corporate Sustainable Management* (Editor: Andrea Marsanich)
PRIV	*Privatisation, Regulation, Antitrust* (Editor: Bernardo Bortolotti)
ETA	*Economic Theory and Applications* (Editor: Carlo Carraro)

2003 SERIES

CLIM	*Climate Change Modelling and Policy* (Editor: Marzio Galeotti)
GG	*Global Governance* (Editor: Carlo Carraro)
SIEV	*Sustainability Indicators and Environmental Valuation* (Editor: Anna Alberini)
NRM	*Natural Resources Management* (Editor: Carlo Giupponi)
KNOW	*Knowledge, Technology, Human Capital* (Editor: Gianmarco Ottaviano)
IEM	*International Energy Markets* (Editor: Anil Markandya)
CSRM	*Corporate Social Responsibility and Management* (Editor: Sabina Ratti)
PRIV	*Privatisation, Regulation, Antitrust* (Editor: Bernardo Bortolotti)
ETA	*Economic Theory and Applications* (Editor: Carlo Carraro)
CTN	*Coalition Theory Network*