Domestic Effects of Environmental Policies with Transboundary Pollution

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1 Introduction

Environmental issues have emerged as one of the central points in the debate over moves towards trade liberalisation (the Single European Market, the Uruguay Round of GATT and especially NAFTA). A large literature has studied the effects of international trade on global pollution. Generally, two effects are pointed out: trade might decrease environmental quality by raising the scale of economy activity and by providing dirty industries incentives to relocate in countries with laxer environmental policies. Conversely, international trade brings income gains which may increase the demand for environmental quality involving new investments in less polluting technologies (Copeland and Taylor, 1995; Bruvoll and Fæhn, 2006).

A third effect of trade liberalisation is to make governments unable to use trade instruments to protect domestic industries. So, governments might seek to weaken their domestic environmental policies as a means of covert protection. Hence, the common wisdom is that free trade leads governments to relax their environmental standards to gain a competitive advantage over their trading partners. Several authors have developed variants of the basic Brander and Spencer (1985) model to show that governments may indeed be tempted to engage in ‘eco-dumping’, that is to say, to soften their environmental policies with respect to the first-best rule of equating the social

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marginal value of pollution with the marginal cost of damage (Conrad, 1993; Rauscher, 1994; Ulph, 1996, 1997). However, as the export tax required in the Bertrand-type model of Eaton and Grossman (1986), strategic distortions of environmental policies sometimes induce over-optimal regulation (Barrett, 1994; Kennedy, 1994). In fact, the results depend strongly on the nature of competition (whether goods are strategic substitutes or strategic complements). This is because the environmental policy is concerned by two goals in these models: targeting domestic emissions while also providing strategic advantages for domestic firms.

However, pollution might cross national borders. Pollution of the Great Lakes in North America and the River Rhine in Europe are two examples of transboundary pollution. In such cases of transboundary external effects, the environmental policy has a triple role to play: targeting domestic emissions, providing strategic advantages for domestic firms and targeting imported pollution. In most of the papers quoted above, the environmental policy aims only one representative sector (one exception is Hoel, 2005). However, empirically environmental constraints are not uniform across sectors. In Europe for example, differentiated taxes on oil products amounts to taxing differently polluting emissions of sectors using this same input (e.g. fishery sector and road transport sector). In some cases, differentiation in emission taxes between sectors is less visible at first glance. One example is the Swedish charge on nitrogen oxides (Swedish Environmental Protection Agency, 2006). The emissions of NO\textsubscript{x} are charged according to a given unit tax without discrimination between firms but the tax revenue is then returned to firms in proportion to their production. So, it follows that the cleaner sector is a financial winner: the unit cost in the clean sector is alleviated with respect to the dirty sector. Following these empirical observations, we use a multi-sector economic model. Consequently a new issue arises involving the distribution of emissions among sectors. So, the main objective of this paper is to evaluate the domestic effects of environmental policies. In particular, we address the question: do the strategic interactions between governments lead to an efficient distribution of emissions among national sectors in each country?

We use a two-country model assuming that there are two production sectors in each country. From a theoretical point of view, these sectors are independent in terms of trade. Hence, firms do not internalise any of the external effects: production choices in one sector are not influenced by the production choices in the other sector. This assumption allows us to identify clearly the impact of regulatory policies on the distribution of emissions between sectors. In our model, representative firms in each sector are duopolies with differentiated products that can be either strategic substitutes or strategic complements. Goods are sold in a third country (e.g. as in Barret, 1994 or Ulph, 1997). Production generates transboundary pollution and we
assume that a country is more sensitive to environmental quality than the other one. The government of each country is in charge of the environmental policy and can either use emission quotas or environmental taxes. We analyse these policies from two different perspectives. First and as usually, regulatory policies are evaluated with respect to the total level of emissions they implement as well as the distribution of these emissions between countries. Second, using our two-sector model, we are able to evaluate environmental policies according to the national level of emissions and their distribution between domestic sectors.

The main results are as follows. Whatever the environmental policy, if the goods of the sector are substitutes, the total amount of polluting emissions is higher than the optimal level. On the other hand, if goods are complements, the total level of pollution may be lower than the optimal level. Examining the distribution of emissions between countries, we show that, whatever the environmental policy, the country very sensitive to pollution will implement an excessively low emission level, whereas the country less concerned by environmental issues will implement an excessively high pollution level. Then, we consider domestic emissions. If both governments use emission quotas, we bring out a domestic efficiency with respect to both the level and the distribution of these emissions within each country. If both governments regulate pollution with a tax policy, this will lead to inefficiencies in both the level of domestic emissions and their distribution between sectors. However, when asymmetric environmental policies across countries are considered, we show that the distortions arising from regulatory policies are not linked to the nature of the instrument used but depend on the governments’ ability to use the instrument in a strategic way. In particular, the quota policy no longer leads to domestic efficiency when the foreign country regulates by taxes. So, a transversal outcome arises from our results: when the foreign country uses tax policy, whatever the environmental policy used by the domestic one, the latter implements inefficiencies in both the level and the distribution of its emissions.

The paper is organized as follows. Section 2 presents the model. In particular, we define four criteria with respect to polluting emissions as well as their distribution between countries and sectors. Section 3 addresses a benchmark situation in which there is no regulatory policy. Section 4 evaluates environmental policies using emission quotas while section 5 considers regulatory policies by means of taxation. Section 6 focuses on the asymmetric case in which countries do not choose the same environmental instrument. Finally, section 7 concludes this paper and proposes directions for future work.
2 The model

We consider a two-country model with two production sectors in each country. These sectors are independent from the trade point of view. In each sector, we assume a differentiated duopoly between the firms of countries a and b which sell their products in a third country.

Firms compete in quantities in a simultaneous game where the functional forms of inverse demands are common knowledge. Using \( p_i^a, p_i^b \) and \( y_i^a, y_i^b \) to denote the price and quantity produced by each firm of sector i (i = 1,2) in countries a and b, we have

- sector 1: \( p_1^a = \alpha_1 - \beta_1 y_1^a - \gamma_1 y_1^b \) and \( p_1^b = \alpha_1 - \beta_1 y_1^b - \gamma_1 y_1^a \)
- sector 2: \( p_2^a = \alpha_2 - \beta_2 y_2^a - \gamma_2 y_2^b \) and \( p_2^b = \alpha_2 - \beta_2 y_2^b - \gamma_2 y_2^a \)

with \( \alpha_i > 0 \) and \( \beta_i \geq |\gamma_i| \geq 0, i = 1,2 \) and for the quantity spaces where prices are positive.

In each sector i = 1,2 the consumers’ willingness to pay for the good produced by the firm of one country is always decreasing in quantity and decreases [increases] with the quantity of the good produced by the firm of the other country when \( \gamma_i > 0 \) [\( \gamma_i < 0 \)]. Hence, in each sector, goods are either substitutes, independent, or complements according to the sign of \( \gamma_i \).

By assuming linear demand, we obtain linear best-response functions that simplify the analytics. However, as far as the results are concerned, the determining factor is not the linearity in itself for the best-response functions but their slope that is negative when goods of a sector are substitutes and positive when goods are complements. Because we can choose \( \alpha_1 \) and \( \alpha_2 \) freely in inverse demands, we normalize the unit cost of production to zero for each firm.

From the pollution point of view, sector 1 is assumed to be cleaner than sector 2. More precisely, transboundary-pollution levels are \( e_1 y_1^a \) and \( e_1 y_1^b \) in sector 1 and \( e_2 y_2^a \) and \( e_2 y_2^b \) in sector 2 with \( e_1 < e_2 \).

We assume country a is more sensitive to pollution than country b. This situation might arise from the greater fragility of the ecosystem in country a and/or a greater interest of its residents for environmental quality. The sensitivity of each country is modelled using two parameters, respectively \( d^a \) and \( d^b \), where \( d^a > d^b \).

Using \( \Pi_i^a \) and \( \Pi_i^b \) to denote the respective profits of the domestic firms in sector i (i = 1,2), the countries’ welfare functions \( W^a \) and \( W^b \) are

\[
W^a(y_1^a, y_1^b, y_2^a, y_2^b) = \Pi_1^a(y_1^a, y_1^b) + \Pi_2^a(y_2^a, y_2^b) - d^a [e_1(y_1^a + y_1^b) + e_2(y_2^a + y_2^b)]
\]

\[
W^b(y_1^a, y_1^b, y_2^a, y_2^b) = \Pi_1^b(y_1^a, y_1^b) + \Pi_2^b(y_2^a, y_2^b) - d^b [e_1(y_1^a + y_1^b) + e_2(y_2^a + y_2^b)].
\]
Equilibria in each sector can be evaluated considering the amounts of production, the levels of emissions and their distribution between countries and sectors. This evaluation is provided from two different perspectives:

- both countries’ global welfare, i.e. maximizing \((W^a + W^b)\) with respect to the total amount and to the distribution of polluting emissions,
- domestic efficiency in each country with respect to the amount and to the distribution of emissions that maximize, respectively, \(W^a\) and \(W^b\) for given choices of production in the foreign country.

We use four evaluation criteria

### 2.1 Optimal amounts of emissions

Maximizing total welfare \(W^a + W^b\) leads to equalize, for each sector, the sum of marginal firms’ profits and the sum of marginal damage of pollution

\[
\frac{\partial \Pi^a_i(y_i^a, y_i^b)}{\partial y_i^a} + \frac{\partial \Pi^b_i(y_i^a, y_i^b)}{\partial y_i^b} = c_i (d^a + d^b) = \frac{\partial \Pi^a_i(y_i^a, y_i^b)}{\partial y_i^a} + \frac{\partial \Pi^b_i(y_i^a, y_i^b)}{\partial y_i^b} \quad i = 1,2
\]

(1)

The four equations allow us to determine the four optimal polluting emissions denoted by \(e_1 y_1^{a*}\), \(e_1 y_1^{b*}\), \(e_2 y_2^{a*}\) and \(e_2 y_2^{b*}\).

### 2.2 Optimal distribution of emissions between countries

Let us consider \(E\) a given amount of pollution generated by both countries. The optimal distribution of emissions \(E\) between countries is the solution of

\[
\text{Maximize } \begin{align*}
W^a(y_1^a, y_1^b, y_2^a, y_2^b) + W^b(y_1^a, y_1^b, y_2^a, y_2^b) \quad \text{subject to } e_1(y_1^a + y_1^b) + e_2(y_2^a + y_2^b) = E
\end{align*}
\]

We obtain

\[
\frac{\partial \Pi_i(y_i^a, y_i^b)}{\partial y_i^a} + \frac{\partial \Pi_i(y_i^a, y_i^b)}{\partial y_i^b} = \frac{\partial \Pi_i(y_i^a, y_i^b)}{\partial y_i^a} + \frac{\partial \Pi_i(y_i^a, y_i^b)}{\partial y_i^b} \quad \text{for } i = 1,2.
\]

(2)

In each sector, the profit functions of rival firms are symmetric. It follows that the optimal distribution of total pollution \(E\) is such that

\[
e_1 y_1^a = e_1 y_1^b \quad \text{and} \quad e_2 y_2^a = e_2 y_2^b.
\]

(2')

### 2.3 Efficient amounts of emissions for a country

For given choices of production in the foreign country, maximizing country \(j\)’s welfare \(W^j\) \((j=a,b)\), requires that the marginal profit and the marginal damage of pollution are equalized for each sector...
\[
\frac{\partial \Pi(y_i^a, y_i^b)}{\partial y_i^a} = e_i^a \text{ and } \frac{\partial \Pi(y_i^a, y_i^b)}{\partial y_i^b} = e_i^b \text{ for } i = 1, 2. (3)
\]

2.4 Efficient distribution of emissions in a country

For given choices of production in the foreign country, let \( E_j^j \) be the domestic polluting emissions in country \( j \) (\( j = a, b \)). The optimal distribution of emissions \( E_j^j \) between sectors in country \( j \) is the solution of

\[
\text{Maximize } W_j(y_1^j, y_2^j) \text{ subject to } e_1^j y_1^j + e_2^j y_2^j = E_j^j \text{ with foreign productions given.}
\]

We obtain

\[
\frac{\partial \Pi(y_i^j, y_i^j)}{\partial y_i^j} = \frac{\partial \Pi_j(y_i^j)}{\partial y_i^j} \text{ for } j = a, b. (4)
\]

3 Equilibrium levels of production without regulation

Each firm chooses its production non-cooperatively, without internalising any external effect. In the third country, the corresponding Nash equilibria \( (y_1^a, y_1^b) \) and \( (y_2^a, y_2^b) \) for sectors 1 and 2 are given by

\[
\frac{\partial \Pi^N(y_i^a, y_i^b)}{\partial y_i^a} = 0 \text{ and } \frac{\partial \Pi^N_i(y_i^a, y_i^b)}{\partial y_i^b} = 0 \text{ for } i = 1, 2 (5)
\]

which leads to

\[
y_1^a = y_1^b = \alpha_1/(2\beta_1 + \gamma_1) \text{ and } y_2^a = y_2^b = \alpha_2/(2\beta_2 + \gamma_2). (5')
\]

Using the criteria specified in section 2, the following proposition is straightforward.

**Proposition 1**

Considering the case without regulation

(a) If goods of the sector are substitutes, the total amount of emissions is higher than the optimal level. If goods are complements, the global level of pollution may be lower than the optimal one.

(b) The total amount of pollution is optimally distributed between countries.

(c) Inefficiency of domestic emissions: given the equilibrium productions in the foreign country, a country could increase its welfare by reducing polluting emissions in the two sectors.

(d) Efficiency for the distribution of domestic emissions: given the equilibrium productions in the foreign country and for an unchanged total level of
domestic pollution, a country cannot increase its welfare by reallocating emissions between domestic sectors.

**Proof.** See appendix A.

The intuition of this proposition is the following. Firms do not take into account the effect of their production on the rival firms’ profits. If goods of sector $i$ are substitutes ($\gamma_i > 0$), this effect is negative. It follows that production, and hence pollution, are over-optimal. If goods of sector $i$ are complements ($\gamma_i < 0$), the effect of a firm’s production on the rival’s profit is positive. For strongly complement goods (for a high value of $|\gamma_i|$) and for a weak environmental damage (for a low value of $e_i(d_{a} + d_{b})$), the emissions are sub-optimal. Moreover, firms do not internalize the negative external effect of their production on the environment. For given choices of production in the foreign country, each country would enhance its welfare if emissions in both sectors decreased.

4 Evaluating a regulatory policy with quotas

In this section, we consider a policy game where governments use environmental quotas as policy instruments. The timing of the game is as follows

- Stage 1: in each country the government chooses emission quotas simultaneously for both domestic sectors.
- Stage 2: the firms simultaneously choose their productions with respect to the legislation.

At the second stage, *if the emission quotas are binding*, firms will use their rights to pollute to the maximum. Consequently, at the first stage of the game, governments know that choosing quotas is equivalent to deciding the production level in both domestic sectors.

At stage 1, the Nash equilibrium $(y_1^a \bar{Q}, y_1^b \bar{Q}, y_2^a \bar{Q}, y_2^b \bar{Q})$ is then characterized by

$$\frac{\partial W(y_1^a, y_1^b, y_2^a, y_2^b)}{\partial y_i^a} = 0 \text{ and } \frac{\partial W(y_1^a, y_1^b, y_2^a, y_2^b)}{\partial y_i^b} = 0 \text{ for } i = 1,2$$

which can be rewritten as

$$\frac{\partial \Pi_i(y_1^a, y_1^b, y_i^q)}{\partial y_i^a} = e_i \ d_a \text{ and } \frac{\partial \Pi_i(y_1^a, y_1^b, y_i^q)}{\partial y_i^b} = e_i \ d_b \text{ for } i = 1,2.$$  \hspace{1cm} (6')

Comparing equations (6') and (5) shows that *quotas are actually binding for firms*.

We obtain the following proposition.
Proposition 2

In both countries, governments use quotas as policy instruments.

(a) If goods of the sector are substitutes, the total amount of emissions is higher than the optimal level. If goods are complements, the global level of pollution may be lower than the optimal one.

(b) The total amount of pollution is not optimally distributed between countries: the country very sensitive to pollution implements an excessively low emission level, whereas the one less concerned with environmental issues implements an excessively high pollution level.

(c) Domestic efficiency: given the production levels in the foreign country, a country cannot increase its welfare by changing its domestic level of emissions or the allocation of these emissions.

Proof. See appendix B.

Result (a) follows from the fact that governments do not take into account the effect of their national productions in the foreign country neither on firms’ profits nor on environmental damage. Let us now consider result (b). Country a evaluates the environmental damage induced by one unit of production in sector i at $e_i^{d_a}$. This country is ‘greener’ than country b. Hence, its evaluation is higher than that retained by country b, that is $e_i^{d_b}$. It follows that productions are such that $y_i^a Q < y_i^b Q$. However, from the social welfare point of view, the unit transboundary environmental damage is $e_i (d^a + d^b)$ whatever the emitting country. Given that profit functions are symmetric, the optimal distribution of productions should satisfy the equality $y_i^a = y_i^b$.

5 Evaluating a regulatory policy with taxes

In this section, we address a policy game in which governments use taxes as environmental policy instruments. The timing of the game is as follows.

– Stage 1: governments choose a pair of taxes simultaneously for their two domestic sectors, respectively, $(t_1^a, t_2^a)$ and $(t_1^b, t_2^b)$.

– Stage 2: firms simultaneously choose their production levels.

- At the second stage, the best-response functions of the firms implemented by the countries a and b, through any values $t_1^a$, $t_2^a$ and $t_1^b$, $t_2^b$, are $y_i^a(y_i^b; t_i^a)$ and $y_i^b(y_i^a; t_i^b)$ for $i = 1, 2$.

This leads to the Nash equilibrium values for productions: $y_i^a(t_i^a, t_i^b)$ and $y_i^b(t_i^a, t_i^b)$ for $i = 1, 2$.

- At the first stage, the countries’ welfare functions are $W_j(t_1^a, t_1^b, t_2^a, t_2^b)$ for $j = a, b$.
It follows the Nash equilibrium values for pairs of taxes: \((t_1^a, t_2^a)\) and \((t_1^b, t_2^b)\).

- Unwinding the game gives the equilibrium \((y_1^a T, y_2^a T, y_1^b T, y_2^b T)\) implemented by the tax policies.

  We prove in appendix that the equilibrium can be characterized by

  \[
  \frac{\partial \Pi_i(y_i^{aT}, y_i^{bT})}{\partial y_i^a} = e d^a - \frac{-\gamma_i}{2b_i} \frac{\partial \Pi_i(y_i^{aT}, y_i^{bT})}{\partial y_i^b} + \frac{-\gamma_i}{2b_i} e d^b \quad \text{and}
  \]

  \[
  \frac{\partial \Pi_i(y_i^{aT}, y_i^{bT})}{\partial y_i^b} = e d^b - \frac{-\gamma_i}{2b_i} \frac{\partial \Pi_i(y_i^{aT}, y_i^{bT})}{\partial y_i^a} + \frac{-\gamma_i}{2b_i} e d^a \quad \text{for } i = 1, 2. \quad (7)
  
  \]

  Then, we obtain the following proposition.

  **Proposition 3**
  
  In both countries, governments regulate pollution with taxation policy.

  (a) If goods of the sector are substitutes, the total emissions are over-optimal. If goods are complements, the total pollution may be sub-optimal.

  (b) The global amount of emissions is not distributed optimally between countries: the country very sensitive to pollution implements an excessively low emission level whereas the one less concerned with environmental issues implements an excessively high pollution level.

  (c) Domestic emissions inefficiency; given the productions in the foreign country, one country could increase its welfare by changing its domestic level of emissions in each of its sectors. More precisely, if goods of the sector are substitutes, the amount of domestic emissions is higher than the efficient level; if goods are complements, the amount of domestic pollution may be lower than the efficient one.

  (d) Domestic distribution inefficiency: given the productions in the foreign country, and without changing its total level of pollution, one country could increase its welfare by reallocating emissions among its domestic sectors.

  **Proof.** See appendix C.

  Considering the relations (7), intuitions of the results are as follows. Government a (as an example) uses taxes to achieve three goals:

  - to make its firms internalize domestic environmental damage generated by their production (the term \(e^a d^a\))
  - to modify strategically best-response functions of their firms in order to increase their equilibrium profits (the term \(\frac{-\gamma_i}{2b_i} \frac{\partial \Pi_i(y_i^{aT}, y_i^{bT})}{\partial y_i^b}\))
  - to reduce the environmental feedback due to transboundary emissions (the term \(\frac{-\gamma_i}{2b_i} e d^b\)).
It follows that confronted with the transboundary character of pollution, countries consider two possibilities:

- The effect of a commercial support, net of the environmental feedback, is positive: \(-\frac{\partial \Pi_i}{\partial y_i} > e_i d^a\). This applies if goods of sector i are substitutes or if goods are complements when \(\frac{\partial \Pi_i^a}{\partial y_i} > e_i d^a\). In this case, government provides a commercial support setting environmental tax lower than the Pigouvian level: \(\frac{\partial \Pi_i(y_i, y_i^b)}{\partial y_i} < e_i d^a\).

- The effect of a commercial support, net of the environmental feedback, is negative: \(-\frac{\partial \Pi_i}{\partial y_i} < e_i d^a\). This applies if goods of sector i are complements with \(\frac{\partial \Pi_i^a}{\partial y_i} < e_i d^a\). In this case, government does not provide any trade support but rather retains a trade penalty, choosing an environmental tax higher than the Pigouvian level: \(\frac{\partial \Pi_i(y_i, y_i^b)}{\partial y_i} > e_i d^a\).

When evaluating domestic efficiency in each country, we consider productions in the foreign country as given. In this case, the only goal of the government is to make its firms internalize environmental damage generated by their production. So, for given productions in the foreign country, the government would set taxes at the Pigouvian levels, and would then implement, in each sector, equality between the marginal profit and the marginal damage of pollution with respect to criterion (3).

6 Domestic efficiency with taxes but not with quotas

In this section, we point out that distortions resulting from regulatory policies are not linked to the instrument used but depend on the possibilities for government to use the instrument in a strategic way.

We consider the policy game in which country a prefers applying an emission-quota policy whereas country b adopts a tax policy. The timing of the game is as follows

- Stage 1: governments choose emission quotas and taxes simultaneously.
- Stage 2: firms choose simultaneously their production levels.

In this new competition context, regulatory policies may have opposite domestic effects compared with those described in the two preceding sections. Now, we anticipate that regulating by taxes may lead to domestic efficiency but regulating by quotas leads to domestic inefficiency.
In order to obtain the result, it is useful to consider the game in which country a does not use regulation (or, equivalently, sets quotas at non binding levels) whereas country b plays a tax policy. Using the result (7) above, we know that in this case the Nash equilibrium \((y^a_i, y^b_i T)\) implemented by the tax policy for sector \(i\) is given by

\[
\frac{\partial \Pi^b_i(y^a_i, y^b_i T)}{\partial y^a_i} = 0 \quad \text{and} \\
\frac{\partial \Pi^b_i(y^a_i, y^b_i T)}{\partial y^b_i} = e_i d_i - \frac{y^a_i}{2\beta} \left[ \frac{\partial \Pi^b_i(y^a_i, y^b_i T)}{\partial y^a_i} - e_i d_i \right].
\]

With no pollution \((e_i = 0)\), the best-response functions of the countries would collapse with the best-response functions of their firms and the Nash equilibrium \((y^a_i, y^b_i T)\) would be the Stackelberg point with the country b as leader (here we recognize the results of Brander and Spencer, 1985 and Eaton and Grossman, 1986).

As \(e_i\) increases, the best-response functions of the countries move to lower quantities. Moreover, relation (8) shows that country b reduces its strategic distortions in order to reduce the environmental feedback due to transboundary emissions. So, the Stackelberg point moves to a lower \(y^b_i T\). It follows that as \(e_i\) increases, depending on the nature of goods, we obtain figure 1 (when goods are substitutes) or figure 2 (when goods are complements).

We draw the figures for a given \(e_i > 0\). \(BR^a_i\) and \(BR^b_i\) are the best-response quantities of countries a and b to foreign productions, \(y^a_i(y^b_i)\) is the best-response function of firm \(i\) in country \(a\) without quota and \(S\) is the Stackelberg point.

6.1 Goods are substitutes

On the line \(BR^b_i\) we put the point V such that \(W^b_i(y^a_i V, y^b_i V)\) equals \(W^b_i(y^a_i S, y^b_i S)\).

Let us now consider the first stage of our policy game in which country a uses an emission-quota policy whereas country b uses a tax policy.

- The best-response policy of country b to a quota higher than \(q_i y^a_i V\) is to implement the Stackelberg point S setting tax lower than the Pigouvian level. However, the best response of this country to a quota lower than \(q_i y^a_i V\) is to set tax at Pigouvian level.

- The isowelfare curve of country a is tangent to the best-response line \(BR^b_i\) at point E. Following the parameters values, \(y^a_i E\) may be under or above \(y^a_i V\). In the first case, the best response of country a to the best-response policy of country b is to select the quota \(q_i y^a_i \cdot E\). In the second case, the best response of country a is to select the quota \(q_i y^a_i V\) because \(W^a_i(y^a_i Y, y^b_i V)\) is higher than \(W^a_i(y^a_i S, y^b_i S)\).
It follows that when goods are substitutes, the equilibrium \((y^a_i, y^b_i)\) with Pigouvian taxes is such that
\[
\frac{\partial \Pi^a(y^a_{iQT}, y^b_{iQT})}{\partial y^a_i} < e_i d^a \quad \text{and} \quad \frac{\partial \Pi^b(y^a_{iQT}, y^b_{iQT})}{\partial y^b_i} = e_i d^b.
\]

### 6.2 Goods are complements

We name \(W\) the point where the line \(BR_b^i\) intersects the firm’s best response in country \(a\) if no quota was used.

Let us consider the first stage of the policy game in which country \(a\) uses quotas and country \(b\) uses taxes.

- The best-response policy of country \(b\) to a quota lower than \(q y^a_i W\) is to set tax at Pigouvian level. A quota \(q y^a_i m\) such that the line \(BR_b\) between \(y^a_i W\) and \(y^a_i S\) is not binding on the line \(BR_b\). It follows that the best response of country \(b\) to a quota \(q y^a_i m\) between \(q y^a_i W\) and \(q y^a_i S\) is to set tax lower than the Pigouvian level in order to implement the point \(m\) where the line \(y^a_i m\) intersects the best-response line \(y^a_i(y^b_i)\) of the foreign firm. Given a quota higher than \(q y^a_i S\), the best response of country \(b\) is to implement the point \((y^a_i S, y^b_i S)\) setting tax lower than the Pigouvian level.
The best response of country $a$ to the best-response policy of country $b$ depends on the per unit environmental damage of production ($e_i d^a$).

With no pollution ($e_i = 0$), the isowelfare curves of country $a$ collapse with the isoprofit curves of its firm and not using quota is better for country $a$.

As $e_i$ increases, the lines $BR_i^a$ and $BR_i^b$ move to lower quantities. Moreover, relation (8) shows that point $S$ moves to lower quantities as well. So, there exists a threshold value for $e_i d^a$ from which the best response of country $a$ to the best-response policy of country $b$ is to select the quota $q_i^a E$. It is the case when the isowelfare curve of level $W^a(y^a_{i S}, y^b_{i S})$ is above the isowelfare curve of level $W^a(y^a_{i E}, y^b_{i E})$.

It follows that when goods are complements, the equilibrium $(y_i^a Q^T, y_i^b Q^T)$ is such that

- low value of $e_i d^a$: $\frac{\partial \Pi^a_i(y_i^{a Q^T}, y_i^{b Q^T})}{\partial y_i^a} = 0$ and $\frac{\partial \Pi^b_i(y_i^{a Q^T}, y_i^{b Q^T})}{\partial y_i^a} < e_i d^b$
- high value of $e_i d^a$: $\frac{\partial \Pi^b_i(y_i^{a Q^T}, y_i^{b Q^T})}{\partial y_i^a} < e_i d^a$ and $\frac{\partial \Pi^b_i(y_i^{a Q^T}, y_i^{b Q^T})}{\partial y_i^a} = e_i d^b$.

Using the criteria (3) and (4), the following proposition is straightforward.
Proposition 4

Country a uses quota policy and country b uses tax policy.

(a) When the foreign country uses a tax policy, a regulatory policy with quotas leads to domestic emissions inefficiency (given the levels of production in country b, country a could increase its welfare by reducing its emissions) and to domestic distribution inefficiency (given the levels of production in country b, and without changing its total level of domestic pollution, country a would be able to increase its welfare by reallocating its emissions between domestic sectors).

(b) When the foreign country uses a quota policy, we must distinguish two cases.

- Goods are complements and create a low environmental damage: a regulatory policy with taxes leads to domestic emissions inefficiency (given the levels of production in country a, emissions in country b are too high) and to domestic distribution inefficiency (given the levels of production in country a, and without changing its total level of domestic emissions, reallocating emissions in country b would be welfare improving).

- Goods are substitutes or goods are complements and create a high environmental damage: a regulatory policy with taxes leads to domestic efficiency (given the levels of production in country a, country b cannot increase its welfare by modifying its domestic emissions or the distribution of these emissions).

Finally, we propose a summary of our results in the following table. Columns restate the four criteria we presented in section 2. Lines represent environmental policies of countries. We distinguish the two polar cases: goods are substitutes and goods are complements with a low emission intensity.
<table>
<thead>
<tr>
<th>No regulation</th>
<th>Global amounts of emissions</th>
<th>Optimality of inter-country distribution of emissions</th>
<th>National emissions</th>
<th>Efficiency of intra-country distribution of emissions</th>
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</thead>
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<tr>
<td>Substituts</td>
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<td>Yes</td>
<td>Too high</td>
<td>Yes</td>
</tr>
<tr>
<td>Complements</td>
<td>Sub-optimal</td>
<td>Yes</td>
<td>Too high</td>
<td>Yes</td>
</tr>
<tr>
<td>Quota - Quota</td>
<td>Substituts</td>
<td>Over-optimal</td>
<td>No</td>
<td>Efficient</td>
</tr>
<tr>
<td>Complements</td>
<td>Sub-optimal</td>
<td>No</td>
<td>Efficient</td>
<td>Yes</td>
</tr>
<tr>
<td>Substituts</td>
<td>Over-optimal</td>
<td>No</td>
<td>Too high</td>
<td>No</td>
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<tr>
<td>Complements</td>
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<td>Too low</td>
<td>No</td>
</tr>
<tr>
<td>Quota - Tax</td>
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<td>No</td>
<td>Quota: Too high</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Tax: Efficient</td>
<td>Quota: No</td>
</tr>
<tr>
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<td></td>
<td>Tax: No</td>
<td>Quota: No</td>
</tr>
<tr>
<td>Complements</td>
<td>Over-optimal</td>
<td>No</td>
<td>Quota: Too high</td>
<td>Quota: No</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Tax: Too high</td>
<td>Tax: No</td>
</tr>
</tbody>
</table>
7 Conclusion

This article analyses environmental regulations for transboundary-polluting activities. In our model, governments can use two types of instruments, emission quotas or environmental taxes. These environmental policies have a triple role to play: targeting domestic emissions, providing strategic advantages for domestic firms and targeting imported pollution. First, we consider symmetric cases where governments use the same environmental instrument. In such a context, we show that the country very sensitive to pollution implements an excessively low emission level whereas the one less concerned with environmental issues implements an excessively high pollution level. This result holds whatever the environmental policy used. When analysing domestic emissions, we find there is domestic efficiency with respect to both the level and distribution of these emissions in the case of the quota instrument; however, if governments regulate pollution with a tax policy, we show that the level of domestic emissions and their distribution among sectors are both inefficient. The last step of the paper is to address the asymmetric case where governments do not choose the same environmental instrument. We point out that distortions arising from regulatory policies are not linked to these policies themselves but depend on the possibilities for governments to use these policies in a strategic way. In particular, the quota policy no longer leads to domestic efficiency when the foreign country does not use quota but regulates by taxes. So, a transversal result arises: when the foreign country uses tax policy, whatever the environmental policy used by the domestic one, this latter implements inefficiencies in both the level and the allocation of its emissions.

A possible extension of this work is to analyse to what extent countries are able to coordinate their environmental policies. Some authors have discussed the impact of harmonizing environmental regulation internationally (Cremer and Gahvari, 2004; MacAusland, 2005; Lai, and Hu, 2008). However, an issue arises involving the acceptance of international agreements by countries. The first difficulty is the free riding problem. Generally, a country might be better off participating in an agreement rather than having no agreement at all. However, even if this country would usually be better off when other countries participate, it may prefer to remain outside the agreement and search for its own self-interest. The second difficulty is that, in some cases, a country might be worse off participating in an agreement than it would be without any agreement. For example, as shown by Kanbur and Keen (1993) in a different context, harmonization to the common optimal policy could harm one country with respect to the non-cooperative outcome. Generally,
environmental agreements are thought of as emission-level contracts. However, in an imperfect competition context, our paper shows that the instruments used matter beyond the environmental agreement. In environmental negotiations, an instrument cannot be preferred or excluded solely on its own merits. It must be evaluated in relation to the strategic trade opportunities that it provides, because the latter motivate strategic distortions that are welfare-reducing.

References


Appendix

A  Proof of proposition 1

(a) To evaluate the total level of emissions in both sectors at the Nash equilibrium, we compare equations (5) and (1). Thus, we distinguish two cases

- Goods of sector $i$ are substitutes ($\gamma_i > 0$). In this case, we have $\partial \Pi_i^b / \partial y_i^a < 0$ and $\partial \Pi_i^a / \partial y_i^b < 0$ in equation (1). Since marginal profit functions are decreasing, we can conclude
  
  $e_i y_i^a N > e_i y_i^a^*$ and $e_i y_i^b N > e_i y_i^b^*$ for $i = 1, 2$.

- Goods of sector $i$ are complements ($\gamma_i < 0$). In this case, we have $\partial \Pi_i^b / \partial y_i^a > 0$ and $\partial \Pi_i^a / \partial y_i^b > 0$ in equation (1). For strongly complement goods (high level of $|\gamma_i|$) and for weak environmental damage (low level of $e_i$), we may have
  
  $\frac{\partial \Pi_i(y_i^a, y_i^b)}{\partial y_i^a} + \frac{\partial \Pi_i(y_i^a, y_i^b)}{\partial y_i^b} > e_i (d^a + d^b)$. 

In this case, the emissions of sector $i$ are sub-optimal.

(b) Nash equilibria associated with sectors 1 and 2 are described in equation (5'). They satisfy the optimality condition (2'). The distribution of total pollution is optimal.

(c) To evaluate domestic levels of emissions, for given choices of production in the foreign country, we need to compare equations (5) and (3). Since the marginal profit functions are decreasing, the levels $y_i^a N$ and $y_i^b N$ are too high in each sector.

(d) Finally, we evaluate the distribution of domestic emissions across sectors. At the Nash equilibrium, marginal profits are nil in each sector. Hence, efficient condition (4) is satisfied.

B  Proof of proposition 2

(a) Comparing equations (6') and (1), we distinguish two cases

- If goods of sector $i$ are substitutes ($\gamma_i > 0$), we have
  
  $\partial \Pi_i^b / \partial y_i^a < 0 < e_i d^b$ and $\partial \Pi_i^a / \partial y_i^b < 0 < e_i d^a$.
It follows that $e_i y_i^a Q > e_i y_i^a a$ and $e_i y_i^b Q > e_i y_i^b b$ for sector i (since marginal profit functions are decreasing).

- If goods of sector i are complements ($\gamma_i < 0$), we have $\partial \Pi^b_i / \partial y_i^a > 0$ and $\partial \Pi^a_i / \partial y_i^b > 0$.

This positive trade effect, coming from the rival firm, may be higher than the environmental damage, that is

$$\partial \Pi^b_i / \partial y_i^a > e_i d^b$$

In this case, we have $e_i y_i^a Q < e_i y_i^a a$ and $e_i y_i^b Q < e_i y_i^b b$ for sector i.

(b) Equation $(2')$ characterizes optimal distribution of any given total amount of emissions: for each sector, productions are the same in both countries. Equilibrium productions resulting from a quota regulation are determined by equations $(6')$

$$y_i^a = \frac{2\beta_i (\alpha_i - e_i d^a) - \gamma_i (\alpha_i - e_i d^b)}{4\beta_i - \gamma_i^2}$$ and $$y_i^b = \frac{2\beta_i (\alpha_i - e_i d^b) - \gamma_i (\alpha_i - e_i d^a)}{4\beta_i - \gamma_i^2}$$

$i = 1, 2$.

These productions are such that

$$y_i^a Q = y_i^b Q = \frac{e_i (d^a - d^b)}{2\beta_i + \gamma_i}$$ for $i = 1, 2$.

Country a is more sensitive to pollution than country b ($d^a > d^b$). Hence, the difference above is negative and $y_i^a Q < y_i^b Q$. Consequently, for each sector, the emission ratio in country a is too low compared with the emission ratio in country b.

(c) We check that the Nash equilibrium $(y_1^a Q, y_2^a Q, y_1^b Q, y_2^b Q)$ characterized by equation $(6')$ satisfies the efficiency conditions $(4)$ and $(5)$.

C Proof of proposition 3

We first prove the relations $(7)$.

- At the second stage, the best-response functions of the firms implemented by the countries a and b, through any values $t_1^a$, $t_2^a$ and $t_1^b$, $t_2^b$ are

$$y_i^a(t_i^b; t_i^a) = \frac{\alpha_i - t_i^a e_i}{2\beta_i} - \frac{\gamma_i}{2\beta_i} y_i^b$$ and $$y_i^b(t_i^a; t_i^b) = \frac{\alpha_i - t_i^b e_i}{2\beta_i} - \frac{\gamma_i}{2\beta_i} y_i^a$$ for $i = 1, 2$.

- At the first stage, the equilibrium pairs of taxes $(t_1^a, t_2^a)$ and $(t_1^b, t_2^b)$ are such that

$$\frac{\partial W^a}{\partial t_i^a} = \frac{\partial \Pi^a_i}{\partial y_i^a} + \frac{\partial \Pi^b_i}{\partial y_i^b} - e_i d_i (\frac{\partial y_i^a}{\partial t_i^a} + \frac{\partial y_i^b}{\partial t_i^b}) = 0$$ and
\[
\frac{\partial W^b_i}{\partial \beta^i} = \frac{\partial \Pi^b_i}{\partial y^a_i} \frac{\partial y^a_i}{\partial \beta^i} + \frac{\partial \Pi^b_i}{\partial y^b_i} \frac{\partial y^b_i}{\partial \beta^i} - e_i d_i \left(\frac{\partial y^a_i}{\partial \beta^i} \frac{\partial y^b_i}{\partial \beta^i} + \frac{\partial y^b_i}{\partial \beta^i}\right) = 0 \text{ for } i = 1, 2.
\]

Using
\[
\frac{\partial y^a_i}{\partial \beta^i} = -\frac{e_i}{2\beta^i} \quad \text{and} \quad \frac{\partial y^b_i}{\partial \beta^i} = -\frac{\gamma - e_i}{2\beta^i} = \frac{\gamma e_i}{2\beta^i} \quad \text{in the first relation, and}
\]
\[
\frac{\partial y^b_i}{\partial \beta^i} = -\frac{e_i}{2\beta^i} \quad \text{and} \quad \frac{\partial y^b_i}{\partial \beta^i} = -\frac{\gamma - e_i}{2\beta^i} = \frac{\gamma e_i}{2\beta^i} \quad \text{in the second relation,}
\]
the Nash equilibrium \((y^a_i, y^b_i, y^a_i, y^b_i)\) implemented by the tax policies can be characterized by
\[
\frac{\partial \Pi^a_i(y^a_i, y^b_i)}{\partial y^a_i} = e_i d_i - \frac{-\gamma}{2\beta^i} \frac{\partial \Pi^a_i(y^a_i, y^b_i)}{\partial y^a_i} + \frac{-\gamma}{2\beta^i} e_i d_i \quad \text{and}
\]
\[
\frac{\partial \Pi^b_i(y^a_i, y^b_i)}{\partial y^b_i} = e_i d_i - \frac{-\gamma}{2\beta^i} \frac{\partial \Pi^b_i(y^a_i, y^b_i)}{\partial y^b_i} + \frac{-\gamma}{2\beta^i} e_i d_i \quad \text{for } i = 1, 2. \tag{7}
\]

We can now prove the proposition 3.

(a) Comparing equations (7) and (1) leads to distinguish two cases.

- If goods of sector \(i\) are substitutes \((\gamma > 0)\), we have \(\frac{\partial \Pi^b_i}{\partial y^a_i} < 0\) and \(\frac{\partial \Pi^b_i}{\partial y^b_i} < 0\). Hence, in equation (7), we have (for \(j,k = a,b\) and \(j \neq k\))
\[
-\frac{\gamma}{2\beta^i} \frac{\partial \Pi^a_i(y^a_i, y^b_i)}{\partial y^a_i} - e_i d_i < 0 \quad \text{and then} \quad \frac{\partial \Pi^a_i(y^a_i, y^b_i)}{\partial y^a_i} < e_i d_i.
\]

Therefore
\[
\frac{\partial \Pi^a_i(y^a_i, y^b_i)}{\partial y^a_i} + \frac{\partial \Pi^b_i(y^a_i, y^b_i)}{\partial y^a_i} < e_i d_i < e_i (d_i + d_i^b).
\]

In sector \(i\), emissions are over-optimal.

- If goods of sector \(i\) are complements \((\gamma < 0)\), we have \(\frac{\partial \Pi^a_i}{\partial y^b_i} > 0\) and \(\frac{\partial \Pi^b_i}{\partial y^a_i} > 0\).

This positive trade effect, coming from the rival firm, may be lower than the environmental damage, that is
\[
\frac{\partial \Pi^a_i}{\partial y^b_i} = e_i d_i \quad \text{and} \quad \frac{\partial \Pi^b_i}{\partial y^a_i} = e_i d_i^b.
\]

In this case, in equation (7) we have (for \(j,k = a,b\) and \(j \neq k\))
\[
-\frac{\gamma}{2\beta^i} \frac{\partial \Pi^a_i(y^a_i, y^b_i)}{\partial y^a_i} - e_i d_i < 0 \quad \text{and so} \quad \frac{\partial \Pi^b_i(y^a_i, y^b_i)}{\partial y^a_i} > e_i d_i.
\]

Marginal profit and \(\frac{\partial \Pi^a_i}{\partial y^b_i} = -\gamma y_i^a\) (here \(\gamma < 0\)) can be high enough to satisfy
\[
\frac{\partial \Pi_i(y_i^{aT}, y_i^{bT})}{\partial y_i^j} + \frac{\partial \Pi_i(y_i^{aT}, y_i^{bT})}{\partial y_i^j} > \varepsilon_i (d^a + d^b) \ j = a,b.
\]

In such a case, emissions are sub-optimal.

(b) Equations (7) determine the equilibrium productions implemented by governments

\[
y_i^{aT} = \frac{2b_i \left( (4b_i^2 - \gamma_i) \left( \alpha_i - e \cdot d_i^a \left( 1 - \frac{\gamma_i}{2b_i} \right) \right) - 2b_i \gamma_i \left( \alpha_i - e \cdot d_i^b \left( 1 - \frac{\gamma_i}{2b_i} \right) \right) \right)}{16b_i^4 - 12b_i^2 \gamma_i^2 + \gamma_i^4}
\]

and

\[
y_i^{bT} = \frac{2b_i \left( (4b_i^2 - \gamma_i) \left( \alpha_i - e \cdot d_i^a \left( 1 - \frac{\gamma_i}{2b_i} \right) \right) - 2b_i \gamma_i \left( \alpha_i - e \cdot d_i^b \left( 1 - \frac{\gamma_i}{2b_i} \right) \right) \right)}{16b_i^4 - 12b_i^2 \gamma_i^2 + \gamma_i^4}
\]

for \( i = 1, 2 \).

These productions are such that

\[
y_i^{aT} - y_i^{bT} = \frac{e(d_i^a - d_i^b)(2b_i - \gamma_i)}{-(4b_i^2 - 2b_i \gamma_i - \gamma_i^2)} \text{ for } i = 1, 2.
\]

The denominator of the expression is negative and \( d_i^a \) is higher than \( d_i^b \); it follows that the difference \( y_i^{aT} - y_i^{bT} \) is negative and \( y_i^{aT} < y_i^{bT} \). But equation (2') requires \( y_i^a = y_i^b \). Hence, for each sector emission ratio in country \( a \) is too low compared to the emission ratio in country \( b \).

(c) To evaluate the efficiency of emissions in both countries, we need to compare equations (7) and (3). We can use the results established at point (a).

- If goods of sector \( i \) are substitutes (\( \gamma_i > 0 \)), we have
  \[
  \frac{\partial \Pi_i(y_i^{aT}, y_i^{bT})}{\partial y_i^j} < e \cdot d_i^j \text{ for } j = a,b.
  \]

  For a given output \( y_i^{aT} \) in country \( k \), country \( j \) should decrease \( y_i^j \) to enhance its welfare.

- If goods are complements (\( \gamma_i < 0 \)), we may have
  \[
  \frac{\partial \Pi_i(y_i^{aT}, y_i^{bT})}{\partial y_i^j} > e \cdot d_i^j \text{ for } j = a,b.
  \]

  In this case, for a given output \( y_i^{aT} \) in country \( k \), country \( j \) should increase \( y_i^j \) to enhance its welfare.

(d) The distribution of domestic emissions in a given country can be analyzed by comparing equations (7) and (4). From equation (7) we can compute...
\[
\frac{\partial \Pi_1(y^a_T, y^b_T)}{\partial y^a_1} - \frac{\partial \Pi_1(y^b_T, y^a_T)}{\partial y^b_1} = \frac{\gamma_1}{2\beta_1} \left[-\gamma_1 y^a_T y^b_T - 1\right] - \frac{\gamma_2}{2\beta_2} \left[-\gamma_2 y^b_T y^a_T - 1\right]
\]
for \( j = a, b \).

Generally, this difference is non-zero and efficiency condition (4) is not satisfied. For a pair of productions \((y^a_T, y^b_T)\) implemented by the government in foreign country \(k\), country \(j\) could increase its welfare by reallocating its emissions \((e; y^a_T + e; y^b_T)\) across domestic sectors.