Environmental fiscal competition under product differentiation and endogenous firm location [*]

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Abstract

The purpose of this paper is to conduct a positive analysis of the effect of the pollution taxation on the cross-country location of firms, on the volume of production and on welfare. In particular, we focus on the environmental problem arising when the production generates strictly local pollution externalities. In this case, although there is no regional spillover of pollution, the environmental problem still affects the interregional or international policy since its national regulation determines the location of production. Thus, we turn our attention to the strategy behavior of the governments, who can compete in terms of their environmental policies in order to maximize the national welfare. Furthermore, we also analyze whether a supranational coordinating the environmental policy of its members can drive welfare up comparing to a situation with tax competition among governments. We show that the results depend crucially on the degree of differentiation between the products supplied by each firm.

Key words: Environmental policy; Tax Competition; Plant Location; Product differentiation

JEL Classification: H7, Q2, R3.

1. **Introduction**

The purpose of this paper is to conduct a positive analysis of the effect of the pollution taxation on the cross-country location of firms, on the volume of production and on welfare. In particular, we focus on the environmental problem arising when the production generates strictly local pollution externalities. In this case, although there are no regional spillovers of pollution, the environmental problem still affects the interregional or international policy since its national regulation determines the location of production. Thus, we turn our attention to the strategy behavior of the governments, who can compete in terms of their environmental policies in order to maximize the national welfare. Furthermore, we also analyze whether a supranational coordinating the environmental policy of its members can drive welfare up comparing to a situation with tax competition among governments.

In the last decade, the policy analysis on environmental issues has abandoned the assumption of exogenous market structure to focus on how the regulation affects firms' discrete decisions such as whether or not to serve another country by exports or by building a new plant in that region.[1] Effectively, in an industry with increasing returns to scale, which in turn are generally associated with imperfect competition, firms have two level of decision. They first choose the location of their production plants, and then they decide the level of production in each plant. Hence, unilateral changes in the environmental policy by a country may alter the location decision of firms. Moreover, the modifications on market structure affect welfare through four channels: they alter the level of pollution, they change the consumer surplus, they change the level of tax revenue (if the environmental regulation consists on pollution taxes), and they change

[1] There are an alternative issue that is how firms' location within a region are affected by environmental policy that tries to regulate pollution in the urban center (see, for instance, Foster, 1987).

the profits of national firms (see Markusen et al., 1993).[2] By following a simulation study, Ulph (1994) shows that the impact of environmental policies can be substantially greater than that estimated by models with exogenous plant location.

A conclusion of the previous analysis is that governments may then act strategically in order to maximize the welfare of their citizens. Markusen et al. (1995) endogenize the environmental policy, so that the governments compete in terms of their environmental policies. The competition between countries may weaken the environmental policy. This eco-dumping sometimes reduces the cross-countries welfare, so that the intervention of some supranational authority coordinating the environmental policies may be socially desirable. Since free trade can provoke movements of plants to those countries with lower environmental standards, this is undoubtedly a central issue in, for instance, the construction of an internal market for the European Community or in the North American Free Trade.

In the present paper we also consider a similar game determining environmental policies. However, our analysis differs from that of Markusen et al. (1995) as we consider product differentiation. The aforementioned authors assume a unique firm producing a homogenous product that chooses to build plants in all countries, in some of the countries, or not produce at all. On the contrary, we are interesting in analyzing how product differentiation affects firms' location and environmental tax competition. For that purpose, we assume that there are two imperfectly competitive firms, and that each of them produces a different product with increasing returns to scale. Changes in the degree of product differentiation alter the intensity of competition among firms, and so they also alter how environmental regulation affects firms' location, consumers' surplus and firms' profits. Therefore, the welfare gains from the coordination of environmental policies depends crucially on the degree of product differentiation

The rest of the model is similar to that introduced by Markusen et al. (1995). As these authors, we assume that there are shipping costs between regions. The existence

[2] Motta and Thisse (1994) assume that the location of the firms is initially given, and then they analyze the conditions under which unilateral changes in environmental policy make delocation of firms more likely.

of these costs is the responsible for the fact that, even when the products are perfect substitutes, each firm choose to produce by locating at different regions despite increasing returns to scale. Strictly local pollution is generated as a by-product of the production. We consider that the environmental policy consists on taxes on regional emissions. The equilibrium is a result of a two-stage game. At the first stage of the game, governments decide the level of pollution taxation in order to maximize welfare. We analyze both the non-cooperative solution and the cooperative solution. In the former each regional government sets strategically the rate of the regional tax in order to maximize the regional welfare, whereas in the later solution the governments coordinate the tax rates in order to maximize the overall welfare. In the second stage of the game, each firm decides where to locate, and then how much to produce.

We assert that the coordination of pollution taxation may generate gains of welfare across countries only if products are substitutes. In this case, firms locate at different countries independently on whether or not the governments coordinate their pollution taxes. However, coordination forces the two countries to set positive taxes since they have small effects on consumer surplus as the competition among firms is strong. This negative effect of pollution taxes on welfare is then smaller than that generated by the reduction on the emissions. On the contrary, when products are complementary firms concentrate in one country independently on whether or not the governments coordinate their pollution taxes. In this case, the cooperative and the non-cooperative solutions result on no pollution taxes in the country that attract both firms. When products are complementary pollution taxes provoke large reduction on consumer surplus since the competition among firms is small in this case. Thus, this negative effect of pollution taxes on welfare dominates the positive effect derived from the decreasing in the emissions.

The paper is organized as follows. Section 2 describes the model and the two-stage game determining the equilibrium. Sections 3 and 4 characterize the solution of the fiscal competition case and that of the fiscal coordination case, respectively. Section 5 briefly discusses the economic interpretation of the results along the paper. Finally, Section 6 concludes the paper.

2. The model

Consider a two-region ($r = A, B$) economy with each region administered by a different government. There are two firms ($f = 1, 2$) producing differentiated goods. Each firm decides in which region will locate its production ($x_f = A$ or $x_f = B$) and generates local pollution in the process of production. We assume that one unit of homogenous pollution is generated in a region for each unit of any good produced in that region. We do not then consider transboundary pollution. The government of both regions may set a pollution tax This decision of imposing the pollution tax can be taken unitarily or cooperatively. For simplicity, we assume that each region sets a pollution tax on each unit of good produced by firms located in the region. Both firms have constant marginal production cost *c* and they face a pollution tax t_r on every unit of pollution they emit. Also, exports are subject to a tariff.

In each region *r* there is a representative consumer that consume both goods 1 and 2, and has the utility function $U_r(q_{1r}, q_{2r}) = \overline{P}(q_{1r} + q_{2r}) - \frac{1}{2}(q_{1r}{}^2 + 2\gamma q_{1r}q_{2r} + q_{1r}{}^2) - \eta Q_r$, where $\overline{P}$ is the choke price, q_{1r} and q_{2r} are the consumption of goods 1 and 2, respectively, and Q_r is the total production of pollution in region r. The goods are substitutes, independent or complements according to whether $\gamma > 0$, $\gamma = 0$ or $\gamma < 0$. The parameter η reflects the constant marginal disutility from pollution. The consumer views the total production of pollution Q_r as exogenous. Maximizing the utility function, we obtain that the inverse demand functions for both goods in a region are given by $p_{1r} = \overline{P} - q_{1r} - \gamma q_{2r}$ and $p_{2r} = \overline{P} - q_{2r} - \gamma q_{1r}$, where p_{1r} and p_{2r} are the corresponding market clearing prices.

Both firms make profits in each region. The profits from sales $\pi_{fr}(x_1, x_2)$ at region *r* by firm *f* are

$$\pi_{fr}\left(x_1,x_2\right)=\left[p_{fr}\left(x_1,x_2\right)-c-t_{x_f}-a_{x_f r}\right]q_{fr}\left(x_1,x_2\right), \qquad (1)$$

where x_f is the location of firm *f*, $q_{fr}\left(x_1,x_2\right)$ is the quantity of good *f* sold in region *r* by firm *f*, $p_{fr}\left(x_1,x_2\right)$ is the corresponding market clearing price of good *f*, t_{x_f} is the pollution tax paid by firm *f* in region x_f, and $a_{x_f r}$ are the tariff costs. Note that tariff is $a_{x_f r}=0$ when $x_f=r$.

We take the duopoly as playing a Cournot-Nash game when choosing their production levels. The problem facing both firms is to maximize the above profit function. Thus, the equilibrium quantities in pure strategies of firm *f* in region *r* are

$$q_{fr}\left(x_1,x_2\right)=\frac{1}{4-\gamma^2}\left[\left(2-\gamma\right)\bar{P}-2\left(t_{x_f}+a_{x_f r}+c\right)+\gamma\left(t_{x_g}+a_{x_g r}+c\right)\right], \qquad (2)$$

where the rival firm *g* is located in region x_g and parameters must be consistent with positive production, $q_{fr}\left(x_1,x_2\right)>0$. Note that this assumption implies that consumers in both regions are served by both firms, implying a total market overlapping. However, note also that in each region the firm with the lowest cost sells a greater quantity of good than its rival.

Substituting (2) into (1), we obtain the equilibrium profits of firm *f* in region *r*

$$\pi_{fr}\left(x_1,x_2\right)=\left(q_{fr}\left(x_1,x_2\right)\right)^2. \qquad (3)$$

Adding the profit functions given by eq. (3), total profits π_f of firm *f* located in region x_f whereas the rival firm *g* is located in region x_g are

$$\pi_f\left(x_1,x_2\right)=\pi_{fA}\left(x_1,x_2\right)+\pi_{fB}\left(x_1,x_2\right). \qquad (4)$$

At this point, we have calculated the equilibrium production levels of both firms fixing the pollution taxes and the locations of firms. Next, we consider a two stage game in which governments first choose their environmental policies, and afterward firms non-cooperatively choose their locations. This game captures the idea that governments decide in anticipation of later competing on locations and quantities. Furthermore, at the first stage of the game, we will consider two scenarios. First one refers to the case where pollution taxes are chosen no cooperatively, and the second one refers to the case where both regions cooperate.

From now on we will assume that the government of each region decides between to set either a pollution tax $t_r = 1$ or no tax $t_r = 0$. Thus, we will consider that each region must decide (unilaterally or cooperatively) whether to impose a Pigovian pollution tax or no pollution tax. Moreover, for simplicity we will also assume that the marginal cost of production c is zero, that the marginal utility cost of pollution η is equal to one, and that the export tariffs $a_{x_f r}$ are one.

3. Firms location for exogenous pollution taxes

In this section we solve the second stage of the game. More precisely, we assume that the governments have already set their tax rates, and firms decide their locations and levels of production given these rates. We will consider two alternative scenarios. The first one refers to the case where goods are perfect substitutes $\gamma = 1$. In the second scenario we consider that goods are complements $\gamma = -1$. The case in which goods are independent $\gamma = 0$ it is trivial since there is no competition among firms.

We are considering two possible locations for each of the two firms: region *A* and region *B*. Thus, we have to distinguish between four possible spatial configurations since $x_1, x_2 \in \{A, B\}$. We will denote these configurations by the pairs (A, B), (B, A), (A, A) and (B, B), where the first and the second element of each pair informs about the location chosen by firm 1 and 2, respectively. The first two configurations arise when firms locate in different regions, whereas the last two configurations arise when both firms locate in the same region.

There are also four different environmental policy scenarios. First, regions *A* and *B* do not charge pollution taxes, $t_A = 0$ and $t_B = 0$, denoted here as (0,0). Second, both regions set pollution taxes, (1,1). Third, region *A* does not set a pollution tax whereas region *B* establishes it, (0,1). Fourth, the symmetrical situation where region *A* has a pollution tax and region *B* does not, (1,0).

3.1. Goods are substitutes

By imposing $\gamma = 1$ in (2), we obtain that the equilibrium quantities in this case are

$$q_{fr}\left(x_1, x_2\right) = \frac{1}{3}\left(\overline{P} - 2\left(t_{x_f} + a_{x_f r}\right) + t_{x_g} + a_{x_g r}\right). \quad (5)$$

The market overlapping assumption requires the condition $\overline{P} > 4$ for the choke price *(positive condition)*. Under this condition each region is served by both firms in all parameter configurations.[3]

Substituting eq. (5) into (3), and using then eq. (4), we obtain the equilibrium profits of each firm under the alternative spatial configurations. Thus, the total profits of firm 1 are

$$\pi_1\left(A,A\right) = \frac{1}{9}\left(\overline{P} - t_A\right)^2 + \frac{1}{9}\left(\overline{P} - t_A - 1\right)^2,$$
$$\pi_1\left(B,A\right) = \frac{1}{9}\left(\overline{P} - 2t_B + t_A - 2\right)^2 + \frac{1}{9}\left(\overline{P} - 2t_B + t_A + 1\right)^2,$$
$$\pi_1\left(A,B\right) = \frac{1}{9}\left(\overline{P} - 2t_A + t_B + 1\right)^2 + \frac{1}{9}\left(\overline{P} - 2t_A + t_B - 2\right)^2,$$

and

$$\pi_1\left(B,B\right) = \frac{1}{9}\left(\overline{P} - t_B - 1\right)^2 + \frac{1}{9}\left(\overline{P} - t_B\right)^2.$$

Moreover, total profits of firm 2 satisfy that $\pi_2\left(A,A\right) = \pi_1\left(A,A\right)$, $\pi_2\left(A,B\right) = \pi_1\left(B,A\right)$, $\pi_2\left(B,A\right) = \pi_1\left(A,B\right)$, and $\pi_2\left(B,B\right) = \pi_1\left(B,B\right)$.

Next, we will analyze the equilibrium spatial configuration for each of the environmental tax scenarios.

Case I. Regions do not set pollution taxes: $t_A = t_B = 0$.

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[3] Note that the production exported by a firm f to a region r is equal to $q_{fr}\left(x_1, x_2\right) = \frac{1}{3}\left(\overline{P} - 4\right)$, when $t_{x_f} = 1$, $a_{x_f r} = 1$, $t_{x_g} = 0$, $a_{x_g r} = 0$ and $x_f \neq x_g$. This parameter configuration represents the situation of the highest competition faced by firm f in serving region r.

If firm 2 is located in region *A*, then firm 1 chooses region *B* (spatial dispersion). From the total profit function of firm 1, we can show that $\pi_1(A,A)-\pi_1(B,A)=\frac{-4}{9}<0$. If firm 2 is now located in region *B*, then firm 1 chooses region *A* (spatial dispersion as well) since $\pi_1(A,B)-\pi_1(B,B)=\frac{4}{9}>0$. By symmetry, firm 2 reacts in the same way to the location decisions of firm 1. Therefore, the equilibrium locations when there is no pollution taxes in the economy involve spatial dispersion: (*A*,*B*) and (*B*,*A*). Since the competition among firms is strong when the goods are substitutes, the absence of environmental taxes leads firms to locate at different regions, such that each of them dominates one regional market.

Case II. Both regions set a pollution tax: $t_A=t_B=1$.

By symmetry, results are the same than in the previous case with no pollution taxes. Therefore, equilibrium locations give spatial dispersion of production: (*A*,*B*) and (*B*,*A*). In this case, competition among firms does not depend on the presence of pollution taxes since both regions set them. Thus, in terms of firm competition this case is similar to the *case I.*

Case III. Region A does not charge a pollution tax whereas region B does it: $t_A=0,\ t_B=1$.

Consider firm 2 is located in region *A*, where there is not a pollution tax, $t_A=0$, then firm 1 reacts choosing also region *A* (spatial concentration), since $\pi_1(A,A)-\pi_1(B,A)=\frac{8(\bar{P}-2)}{9}>0$. If we consider now firm 2 chooses region *B*, where there is a pollution tax, $t_B=1$, then firm 1 locates in region *A* with no tax. By symmetry, we will obtain the same reaction function for firm 2, i.e., this firm will choose the region with no tax.

From the previous result, we can conclude that the equilibrium location, when a region has no pollution tax whereas the other region sets a pollution tax, implies the spatial concentration of production in the region with no tax. The tax scenario analyzed previously would correspond to concentration in region *A*: (*A*,*A*). An analogous result would be obtained if region *A* sets a pollution tax, $t_A = 1$, and region *B* no ($t_B = 0$). In this last scenario, region *B* would attract both the firms: (*B*,*B*). In these two cases, even that the competition is strong, firms prefer to locate in the same region in order to avoid the tax cost.

As a summary, we can conclude that two firms producing perfect substitute goods prefer the spatial dispersion of production trying to avoid competition as far as regions faces the same tax policy, whereas they will concentrate in the region with no pollution tax when regions differ in their tax policies.

3.2. Goods are complements

In this section, we analyze the second stage of game when goods are complements, $\gamma = -1$. We will proceed as in the previous subsection. Since the algebra of this model when goods are complements is similar to the model with substitute goods, we limit ourselves to give the equilibrium strategies. Thus, the equilibrium outputs sold by firms to each region are

$$q_{fr}\left(x_1, x_2\right) = \frac{1}{3}\left(3\overline{P} - 2\left(t_{x_f} + a_{x_f r}\right) - t_{x_g} - a_{x_g r}\right). \tag{6}$$

The market overlapping assumption requires now the condition $\overline{P} > 2$ for the choke price *(positive condition)*.[4]

Substituting eq. (6) into (3), and using then eq. (4), we obtain the equilibrium profits of each firm under the alternative spatial configurations. Thus, the total profits of firm 1 are

$$\pi_1\left(A, A\right) = \frac{1}{9}\left(3\overline{P} - 3t_A\right)^2 + \frac{1}{9}\left(3\overline{P} - 3t_A - 3a_B\right)^2,$$

[4] Note that the production exported by a firm f to a region r is equal to $q_{fr}\left(x_1, x_2\right) = \frac{1}{3}\left(3\overline{P} - 6\right)$, when $t_{x_f} = 1$, $a_{x_f r} = 1$, $t_{x_g} = 0$, $a_{x_g r} = 0$ and $x_f \neq x_g$. This parameter configuration represents the situation of the highest competition faced by firm f in serving region r.

$$\pi_1(A,B)=\frac{1}{9}\left(3\overline{P}-2t_A-t_B-a_A\right)^2+\frac{1}{9}\left(3\overline{P}-2t_A-t_B-2a_B\right)^2,$$

$$\pi_1(B,A)=\frac{1}{9}\left(3\overline{P}-2t_B-t_A-2a_A\right)^2+\frac{1}{9}\left(3\overline{P}-2t_B-t_A-a_B\right)^2,$$

and

$$\pi_1(B,B)=\frac{1}{9}\left(3\overline{P}-3t_B-3a_A\right)^2+\frac{1}{9}\left(3\overline{P}-3t_B\right)^2.$$

Moreover, the total profit function of firm 2 satisfies $\pi_2(A,A)=\pi_1(A,A)$, $\pi_2(A,B)=\pi_1(B,A)$, $\pi_2(B,A)=\pi_1(A,B)$, and $\pi_2(B,B)=\pi_1(B,B)$.

Both firms choose simultaneously and non-cooperatively their locations conditional to the environment policies established by the regions. Next, we will analyze the equilibrium spatial configuration for each tax scenario.

Case I. Regions do not charge pollution taxes: $t_A=t_B=0$.

If firm 2 is located in region *A*, then firm *A* chooses region *A* (spatial concentration) since we obtain that $\pi_1(A,A)-\pi_1(B,A)=\frac{4}{9}>0$. When firm 2 is located in region *B*, then firm 1 chooses region *B* (spatial concentration) since $\pi_1(A,B)-\pi_1(B,B)=\frac{-4}{9}<0$. By symmetry, firm *B* will react in the same way to the location decisions of firm *A*. Therefore, the equilibrium locations of firms when there is no pollution taxes in the economy involves spatial concentration of production: (*A*,*A*) and (*B*,*B*).

Case II. Both regions set a pollution tax: $t_A=t_B=1$.

By symmetry, results are the same than in the previous case with no pollution taxes. Therefore, equilibrium locations imply spatial concentration of production: (*A*,*A*) and (*B*,*B*). As in the case of substitute goods, a uniform taxation of pollution across regions does not alter the degree of competition among firms, so that the equilibrium location coincides with that in the absence of taxes.

Case III. Region A does not charge a pollution tax whereas region B does it: $t_A = 0, t_B = 1$.

Consider firm 2 is located in region *A* where there is no pollution tax, then firm 1 reacts choosing also region *A* (spatial concentration), where there is not pollution tax since $\pi_1(A,A) - \pi_2(B,A) = \frac{8(3\bar{P}-2)}{9} > 0$. On the contrary, if we consider that firm 2 chooses region *B*, where there is a pollution tax, then firm 1 locates in region *A* with no pollution taxes (spatial dispersion) since $\pi_1(A,B) - \pi_2(B,B) = \frac{8(3\bar{P}-4)}{9} > 0$. By symmetry, we will obtain the same reaction function for firm 2, i.e., this firm will always choose the region with no tax.

From the previous result, we can say that the equilibrium location, when a region has no pollution tax whereas the other region sets a pollution tax, is that production concentrates in the region with no tax. The tax scenario analyzed previously would correspond to concentration in region *A*: (*A*,*A*). An analogous result would be obtained if region *A* sets a pollution tax, $t_A = 1$, and region *B* does not, $t_B = 0$. In this last scenario, region *B* would attract both firms: (*B*,*B*). Since complementarity between goods forces firms to locate in the same region in absence of taxes, in a scenario of differentiated pollution taxation across regions, firms choose to locate in the region that does not set taxes.

As a summary, we can conclude that two firms producing complement goods prefer the spatial concentration of production under any regional configuration of the environmental taxation.

Next section shows the solutions of the first stage of the game when regions choose the environmental policy. As we said, we will consider two situations. First, regions choose non-cooperatively and simultaneously whether or not they impose a pollution tax in order to maximize the welfare of their respective regions. Second, governments decide to cooperate to maximize the overall welfare across regions.

4. The Governments' Problem

The role of the regional governments in this economy is to decide whether or not to set a pollution tax in order to maximize the social welfare of their respective regions. In doing so, governments anticipate how firms will react after they set their respective pollution taxes. Evidently, since the location of firms depends on the decisions of both governments, the social welfare of a region also depends on the pollution tax of the other region. Let us denote by $W_r\left(t_A, t_B\right)$ the welfare of region r as governments of regions A and B have set pollution tax rates t_A and t_B, respectively.

As is standard, we assume that the welfare of each region is given by the sum consumer surplus, profits, tax and tariff revenues, and in our case, pollution costs. First, it is easily to find that consumer surplus in region *r* is given by

$$CS_r = \int_0^{q_{1r}} \left(\overline{P} - q - \gamma q_{2r}\right) dq - \left(\overline{P} - q_{1r} - \gamma q_{2r}\right) q_{1r} +$$
$$+ \int_0^{q_{2r}} \left(\overline{P} - q_{1r} - \gamma q\right) dq - \left(\overline{P} - q_{1r} - \gamma q_{2r}\right) q_{2r}.$$

Second, total profits of a firm f located in region r are given by π_f in eq. (4). Third, pollution tax revenues obtained by the government of region r are simply $t_r = \{0,1\}$ times the total production in region r, while tariffs revenues are just the exports of region *r* since we have normalized the tariff rate a_r to 1. Finally, since the marginal pollution cost is constant and equal to one, total emission costs coincides with the production in region *r*.

As mentioned before we consider two different games: a non-cooperative game, where governments compete in pollution taxes, and a cooperative game, where governments jointly decide pollution taxes. The next two sections present these two games.

5. Non-cooperative pollution taxation equilibria

We take regions as playing a Nash game when choosing their pollution taxes t_r. At this stage, each region decides unilaterally whether or not to establish a pollution tax (i.e., $t_r = 1$ or $t_r = 0$). The problem facing by a government of a region r consists on choosing $t_r \in \{0,1\}$ to maximize the welfare of the region, which is given in this case by

$$W_r(t_A, t_B) = CS_r + \text{Profits}_\text{r} + \text{Tariff}_\text{r} + (1 - t_r)Q_r \tag{7}$$

with all parts of $W_r(t_A, t_B)$ defined as before in Section 4.

5.1. Goods are substitutes

As a previous step to obtain the equilibrium in the game between governments, we will derive the reactions functions of each government when goods are substitutes, i.e., $\gamma = 1$. More precisely, we will assume that government of region B set their pollution tax, and then we compute the strategy followed by the government of region A. By symmetry, we can derive the reaction function of government of region B.

Case I. Region B does not charge pollution tax: $t_B = 0$.

As we know from the results of the second stage of the game in Section 3, if region *A* also decides not to charge a pollution tax, both firms locate at different regions. Without loss of generality, we assume that in this case firm 1 locates in region *A* and firm 2 does in region *B*. Thus, from (5) equilibrium supply of firm 1 in each market is $q_{1A}(A,B) = \frac{1}{3}(\overline{P} + 1)$ and $q_{1B}(A,B) = \frac{1}{3}(\overline{P} - 2)$, whereas the equilibrium supplies of firm 2 satisfy that $q_{2A}(A,B) = q_{1B}(A,B)$ and $q_{2B}(A,B) = q_{1A}(A,B)$. Given these equilibrium quantities, the welfare function in region *A* with no taxes is then

$$\begin{aligned} W_A(0,0) &= CS_A + \pi_{1A}(A,B) + q_{2A}(A,B) - q_{1A}(A,B) - q_{1B}(A,B) \\ &= \frac{1}{6}\left(3 - 4\overline{P} + 2\overline{P}^2\right). \end{aligned} \tag{8}$$

On the contrary, if region A charges a pollution tax, $t_A = 1$, then firms concentrate in region B where there is no pollution tax. In this case, the equilibrium quantities obtained at the previous stage of the game are $q_{1A}(B,B) = \frac{1}{3}(\overline{P} - 1)$, $q_{1B}(B,B) = \frac{\overline{P}}{3}$, $q_{2A}(B,B) = q_{1A}(B,B)$, and $q_{2B}(B,B) = q_{1B}(B,B)$. Therefore, in this case the welfare function of region A is then

$$\begin{aligned} W_A(1,0) &= CS_A + q_{1A}(B,B) + q_{2A}(B,B) \\ &= \frac{1}{9}\left(-5 + 4\overline{P} + \overline{P}^2\right). \end{aligned} \tag{9}$$

Comparing (8) and (9) we obtain that $W_A(0,0) > W_A(1,0)$, as long as we imposee that $\overline{P} > 4$ (*positive condition*: all the equilibrium quantities are strictly positive). Therefore, when region B does not set a pollution tax on production to firms established in there, region A neither impose a tax on pollution as the best strategy to maximize the regional welfare. This fact implies a spatial dispersion of firms between both regions as a way of reducing the degree of competition between them.

Case II. Region B is charging a pollution tax: $t_B = 1$.

As far as region A does not impose a pollution tax, $t_A = 0$, firms concentrate in the region with no taxes. Thus, from (5) the equilibrium quantities supplied by both firms satisfies that $q_{1A}(A,A) = \frac{\overline{P}}{3}$, $q_{1B}(A,A) = \frac{1}{3}(\overline{P} - 1)$, $q_{2A}(A,A) = q_{1A}(A,A)$ and $q_{2B}(A,A) = q_{1B}(A,A)$. Therefore, in this case the welfare function of region A is then

$$\begin{aligned} W_A(0,1) &= CS_A + \pi_{1A}(A,A) + \pi_{2A}(A,A) - q_{1A}(A,A) - q_{1B}(A,A) - q_{2A}(A,A) - q_{2B}(A,A) \\ &= \frac{1}{9}\left(8 - 16\overline{P} + 5\overline{P}^2\right). \end{aligned} \quad .(10)$$

On the contrary, if region A also charges a pollution tax, $t_A = 1$, firms locate at different regions. Without lose of generality, we consider that firm 1 locates in region A whereas firm 2 sites its production in region B. The equilibrium quantities sold by the firms in each region are in this case then $q_{1A}(A,B) = \frac{\overline{P}}{3}$, $q_{1B}(A,B) = \frac{1}{3}(\overline{P} - 3)$,

$q_{2B}(A,B) = q_{1A}(A,B)$, and $q_{2A}(A,B) = q_{1B}(A,B)$. Therefore, the welfare function in region *A* is then

$$\begin{aligned} W_A(1,1) &= CS_A + \pi_{1A}(A,B) + q_{2A}(A,B) \\ &= \frac{1}{6}\left(3 - 4\overline{P} + 2\overline{P}^2\right). \end{aligned} \tag{11}$$

By taking difference between (11) and (10), we obtain

$$W_A(0,1) - W(1,1) = \frac{1}{18}\left(7 - 20\overline{P} + 4\overline{P}^2\right). \tag{12}$$

On the one hand, when $\overline{P} < \frac{1}{2}\left(5 + 3\sqrt{2}\right) = 4.62$, the value of the region *A*'s welfare is higher with taxes than without them, $W_A(0,1) < W_A(1,1)$. This means that, as far as region *B* charges a pollution tax, region *A* reacts by establishing a tax as the rival region. On the other hand, if $\overline{P} > \frac{1}{2}\left(5 + 3\sqrt{2}\right) = 4.62$, the difference (12) is positive, which implies that region *A* does not set any pollution tax. The intuition of this result lies in the fact that the choke price informs about the consumer's willingness to pay for goods. The larger that price, the higher the consumer's willingness to pay is. Thus, if the choke price is sufficiently low, the competition among firms is too high so that the region A does not obtain enough profits from eliminating the pollution tax in order to offset the increase of pollution costs and the loss of tax revenues. Therefore, setting positive pollution taxation is an optimal respond of region A when the other region has also decided to charge a pollution tax.

Given the reaction function of region *A*, and since by symmetry region *B* would react in the same way, the next result summarizes the equilibrium solution of the first stage game between governments.

RESULT 1.- *When goods are substitutes, the equilibrium solution of the two-stage game described in Section 2 satisfies:*

(a) If $\overline{P} < 4.62$*, then regions establish the same environmental policy,* $(t_A, t_B) = (0,0)$ *or* $(t_A, t_B) = (1,1)$*, and there is spatial dispersion of production,* $(x_1, x_2) = (A, B)$ *or* $(x_1, x_2) = (B, A)$.

(b) If $\overline{P} > 4.62$*, then regions do not charge pollution taxes on production,* $(t_A, t_B) = (0,0)$*, and there is spatial dispersion of production,* $(x_1, x_2) = (A, B)$ *or* $(x_1, x_2) = (B, A)$.

Figure 1 also summarizes the reaction functions of each government and the Nash equilibrium of this first stage game. The analysis of this subsection shows that when goods are substitutes, the non-cooperative pollution taxation equilibria consist on a uniform taxation across countries, and then a spatial dispersion of production. In particular, the absence of cooperation between regions may lead to a positive taxation of pollution in both regions.

5.2. Goods are complementaries

In Section 3 we have shown that when goods are complements firms concentrate their production in a region independently of the environmental policy configuration. This means that when governments set the same environmental tax policy, $(t_A, t_B) = (0,0)$ or $(t_A, t_B) = (1,1)$, there are multiple equilibrium plant configuration. In particular, there are the following four equilibrium configurations:

a) If $(t_A, t_B) = (0,0)$ or $(t_A, t_B) = (1,1)$ then $(x_1, x_2) = (A, A)$.
b) If $(t_A, t_B) = (0,0)$ or $(t_A, t_B) = (1,1)$ then $(x_1, x_2) = (B, B)$.
c) If $(t_A, t_B) = (0,0)$ then $(x_1, x_2) = (A, A)$, and if $(t_A, t_B) = (1,1)$ then $(x_1, x_2) = (B, B)$.
d) If $(t_A, t_B) = (0,0)$ then $(x_1, x_2) = (B, B)$, and if $(t_A, t_B) = (1,1)$ then $(x_1, x_2) = (A, A)$.

Hence, in principle we must analyze all these cases to establish the equilibrium solution of the first stage game between governments. However, once the results for one case have been characterized, the results for the other three cases follow directly. Therefore, in the analysis that follows we will start by assuming that firms will concentrate in region *A* when both regions decide to establish the same environmental policy. After having characterized this case, we extend the results for the other three cases described above.

We first derive the reaction function of region *A*.

Case I. Region B does not charge a pollution: $t_B = 0$.

If region *A* decides also not to set a pollution tax, firms will concentrate in region *A*. Hence, in this case welfare function in region *A* is

$$\begin{aligned} W_A(0,0) &= CS_A + \pi_{1A}(A,A) + \pi_{2A}(A,A) \\ &\quad - q_{1A}(A,A) - q_{1B}(A,A) - q_{2A}(A,A) - q_{2B}(A,A) \end{aligned} . \tag{13}$$

On the contrary, if region *A* establishes a pollution tax, $t_A = 1$, firms will concentrate in region *B*, where there is no pollution tax. In this case, the welfare function of region *A* is

$$W_A(1,0) = CS_A + q_{1A}(B,B) + q_{2A}(B,B). \tag{14}$$

The difference between (13) and (14) shows that $W_A(0,1) > W_A(1,0)$ assuming $\overline{P} > 2$ (*positive condition*). Therefore, if region *B* does not set a pollution tax on production to firms established there, region *A* will neither set a tax on, which results in the spatial concentration of firms in region *A*.

Case II. Region B charges a pollution: $t_B = 1$.

As far as region *A* does not impose a pollution tax, $t_A = 0$, firms will locate in region *A* where there is no taxes. Thus, in this case, the welfare function of region *A* is then

$$W_A(0,1) = CS_A + \pi_{1A} + \pi_{2A} - q_{1AA} - q_{1AB} - q_{2AA} - q_{2AB}. \tag{15}$$

On the contrary, if $t_A = 1$, then firms will locate in region *A* by assumption since both regions establish the same environmental policy. In this case, the welfare function of region *A* is then

$$W_A(1,1) = CS_A + \pi_{1A} + \pi_{2A}. \tag{16}$$

By taking differences between (15) and (16), we obtain that $W_A(0,1) > W_A(1,1)$ as $\overline{P} > 2$ (*positive condition*). Therefore, if region *B* set a pollution tax on production to firms established there, region *A* will not set a tax on, which results in the spatial concentration of firms in region *A*. Since goods are complements, the competition among firms is too small so as the region *A* obtain enough profits from eliminating the pollution tax in order to offset the increase of pollution cost derive of concentration of firms there and the loss of tax revenues. Therefore, the optimal respond of region *A* is not to charge positive pollution taxation when the other region has also decided to charge a pollution tax.

At this point we have derived the reaction function of region *A*, and we can conclude that this region will never set a pollution tax to the firms that locate in its yard independently of the environmental policy decide by region *B*. Next we calculate the reaction function of region *B*.

Case I. Region A does not charge pollution tax: $t_A = 0$.

As long as region A does not establish a pollution tax, $t_A = 0$, by assumption firms always will locate in this region independently of the tax policy chosen by region *B*. Therefore, region *B* is indifferent between fixing a pollution tax, $t_B = 0$, or not, $t_B = 1$.

Case II. Region A does charge pollution tax $t_A = 1$.

If region *A* establishes a pollution tax, $t_A = 1$, then region *B* will concentrate all the production when this region does not charge a pollution tax, $t_B = 0$. Therefore, in this case the social welfare in region *B* is in this case

$$W_B\left(1,0\right) = CS_B + \pi_{1B} + \pi_{2B} - q_{1BB} - q_{1BA} - q_{2BB} - q_{2BA}. \qquad (17)$$

On the contrary, by assumption region *A* will concentrate all the production if region *B* decides to set a pollution tax, $t_B = 1$. In this case the welfare function in region B is

$$W_B\left(1,1\right) = CS_B + q_{1AB} + q_{2AB}. \qquad (18)$$

By differencing (17) and (18), we obtain that $W_B(1,0) > W_B(1,1)$. Therefore, as a response to the decision of region *A* of charging a pollution tax, region *B* will optimally react by choosing no pollution tax. The intuition of this result follows by using the same arguments given before to explain the reaction function of region *A*. Since goods are complements, the competition among firms is too small so as the region *B* obtain enough profits from eliminating the pollution tax in order to offset the increase of pollution cost derive of concentration of firms there and the loss of tax revenues.

As a summary, the equilibrium environmental policies are $(t_A, t_B) = (0,0)$ and $(t_A, t_B) = (0,1)$, i.e., region *A* does not set a pollution tax, and then this region concentrates all the production of the economy, $(x_1, x_2) = (A, A)$. Remember that this result was obtained by assuming that firms concentrate in region *A* in the case of uniform pollution taxation across regions. We can now easily extend this result to the other cases of equilibrium plant configurations mentioned at the beginning of this subsection. First, case (c) shows the same solution than case (a) analyzed before. In this situation the equilibrium environmental policies are $(t_A, t_B) = (0,0)$ and $(t_A, t_B) = (0,1)$, and both firms locate in region *A*, $(x_1, x_2) = (A, A)$. Second, cases (b) and (d) are the symmetrical ones of case (a). In particular, the equilibrium tax policies are $(t_A, t_B) = (0,0)$ and $(t_A, t_B) = (1,0)$, which implies the spatial concentration of firms in region *B*, $(x_1, x_2) = (B, B)$. Figure 2 illustrates the reaction functions of each government and the Nash equilibrium of this first stage game for each possible equilibrium location of firms that may arise when there is a uniform pollution taxation across regions.

From the reaction functions of both governments described above, the next result describes the Nash equilibrium of the first stage game between governments when goods are complements.

RESULT 2.- *There are four alternative equilibrium solutions of the two-stage game:*

(a) $(t_A, t_B) = (0,0)$ *and* $(x_1, x_2) = (A, A)$*: regions do not set pollution taxes and firms concentrate their production in region A.*

(b) $\left(t_A, t_B\right) = (0,1)$ *and* $\left(x_1, x_2\right) = (A, A)$ *: region A does not set pollution taxes and region B does it, so that firms concentrate their production in region A.*

(c) $\left(t_A, t_B\right) = (0,0)$ *and* $\left(x_1, x_2\right) = (B, B)$ *: regions do not set pollution taxes and firms concentrate their production in region B.*

(d) $\left(t_A, t_B\right) = (1,0)$ *and* $\left(x_1, x_2\right) = (B, B)$ *: region B does not set pollution taxes and region A does it, so that firms concentrate their production in region B.*

The solution of the game involves concentration of firms in one of the regions with no pollution taxes independently of the tax policy establish by the rival firm. When goods are complements, the competency between firms located in the same region is sufficiently small, so that increasing returns to scale force firms to concentrate their locations. Evidently, firms will choose that region without pollution tax to locate their plants. Hence, governments use the pollution taxation in order to compete among them for attracting the firms to their respective territories. This fiscal competition leads to an equilibrium situation where at least one of the regions does not charge a pollution tax.

6. Cooperative pollution taxation equilibria

We address the issue of optimal environmental policy in an institutional context where the decision of whether or not to establish a pollution tax is now taken cooperatively by both regions. More precisely, both regions decide to constitute a supranational authority that by delegation of regions determines the environmental policy that each region must set. The objective of this supranational authority is to choose t_A and t_B in order to maximize the global social welfare of regions, which is given by

$$\begin{aligned} W\left(t_A, t_B\right) = &\ \mathrm{CS}_A + \mathrm{CS}_B + \mathrm{Profits}_A + \mathrm{Profits}_\mathrm{B} \\ &+ \mathrm{Tariff}_A + \mathrm{Tariff}_B + \left(t_A - 1\right)\mathrm{Q}_A + \left(t_B - 1\right)\mathrm{Q}_B, \end{aligned} \tag{19}$$

with all parts of $W_r(t_A, t_B)$ defined as before in Section 4.

Characterizing the equilibrium solution of the two-stage game is now easy. In this situation, since there is no fiscal competition, this aforementioned solution follows directly from the solution of the second stage of the game given in Section 3 when the supranational authority set the environmental taxation. This is the strategy followed to state the next two results that characterize the equilibrium solutions of the two-stage game for two particular cases where goods are substitutes and complements.

RESULT 3.- *Consider that goods are perfect substitutes, then the equilibrium of the two-stage game is given by* $(t_A, t_B) = (1,1)$ *and either* $(x_1, x_2) = (A, B)$ *or* $(x_1, x_2) = (B, A)$*, i.e, both regions must charge a pollution tax and firms locate at different regions.*

Proof.- To prove this result, one must compare the overall welfare across regions, given by (19), obtained in each of the four environmental scenarios that the supranational authority may decide.

(i) If $(t_A, t_B) = (0,0)$, then firms locate at different regions. Hence, the welfare function takes the value $W(0,0) = (1/3)\left(3 - 4\overline{P} + 2\overline{P}^2\right)$.

(ii) If $(t_A, t_B) = (0,1)$, then both firms concentrate in the region *A*. Therefore, we obtain $W(0,0) = (1/3)\left(3 - 4\overline{P} + 2\overline{P}^2\right)$.

(iii) If $(t_A, t_B) = (1,0)$, then by symmetry we obtain the same global welfare as in the previous case, but now both firms locate at region *B*.

(iv) If $(t_A, t_B) = (1,1)$, then firms locate at different regions . Thus, the value of the welfare function is then $W(1,1) = (1/9)\left(5 - 8\overline{P} + 6\overline{P}^2\right)$.

By comparing the previous four the four values for the global welfare, we directly obtain the result. Q.E.D.

The cooperative solution and the competitive solution may not coincide. Figure 3 compares the two solutions. The uniform taxation of pollution in both regions now is equilibrium since regions get involved in fulfilling the mandate from the supranational authority. Given this regions' compromise, pollution taxes have small effects on consumer surplus since the competition among firms is strong when goods are perfect substitutes. The negative effect of pollution taxes on welfare is then smaller than the welfare gain from the reduction on emissions.

RESULT 4.- *Consider that goods are perfect complements, then the equilibrium solutions of the two-stage game consist on spatial concentration of firms in a region without pollution taxes, independently of the tax policy set for the other region. In particular, there are the following alternative solutions:*

(a) $\left(t_A, t_B\right) = (0,0)$ *and either* $\left(x_1, x_2\right) = (A, A)$ *or* $\left(x_1, x_2\right) = (A, A)$.

(b) $\left(t_A, t_B\right) = (0,1)$ *and* $\left(x_1, x_2\right) = (A, A)$.

(c) $\left(t_A, t_B\right) = (1,0)$ *and* $\left(x_1, x_2\right) = (B, B)$.

Proof.- To prove this result, one must compare the overall welfare across regions, given by (19), obtained in each of the four environmental scenarios that the supranational authority may decide.

(i) If $(t_A, t_B) = (0,0)$, then firms locate at one of the regions. In any case, the welfare function takes the value $W(0,0) = 2 - 6\overline{P} + 4\overline{P}^2$.

(ii) If $(t_A, t_B) = (0,1)$, then both firms concentrate in the region *A*. Thus, we obtain that the global welfare takes the same value as in the previous case.

(iii) If $(t_A, t_B) = (1,0)$, then both firms concentrate in the region *B*. Thus, we obtain that the global welfare takes the same value as in the previous cases.

(iv) If $(t_A, t_B) = (1,1)$, then firms locate at either region A or B . Thus, the value of the global welfare is equal to $W\left(1,1\right) = 6 - 10\overline{P} + 4\overline{P}^2$.

By comparing the previous four the four values for the global welfare, we directly obtain the result. Q.E.D.

The cooperative solution and the competitive solution do now coincide. Figure 4 compares the two solutions for the entire set of equilibrium spatial configuration that may arise in the second stage of the game under uniform environmental taxation across regions. When goods are complements, pollution taxes provoke a large reduction on consumer surplus since the competition among firms is small in this case. Thus, this negative effect of pollution taxes on welfare dominates the positive effect derived from the decreasing in emissions.

A final question that must analyze is whether the equilibrium solutions characterized by the two previous results for the cooperative case dominates in the Pareto sense to the equilibrium solutions obtained under non cooperation among governments. In other words, in view of the results obtained in both institutional contexts, it remains to determine whether regions are willing to delegate in a supranational authority the capacity of setting their pollution taxes. In order to answer this question, one must follow an analysis that compares the welfare obtained by each region under each of the institutional scenarios. (To be completed).

7. Conclusions and extensions

This paper analyzes the effects of pollution taxation on the cross-country location of firms and on welfare with a model that encompasses different degrees of product differentiation. As an added value to literature, the model demonstrates that plant location is not only a function of environmental policy but also a function of the degree of product differentiation. Further, the model incorporates an endogenous determination of pollution taxes in the two regions as the outcome of a game between regional governments. Thus, governments can compete in terms of environmental policy in order to maximize the regional welfare. In this sense, the model illustrates that the welfare gains from coordination of environmental policy across regions also depends crucially on whether products are substitutes or complements. The environmental policy determined in a competitive scenario is the same as that determined in a cooperative scenario when goods are complements, whereas if the good are substitutes the policy determined under both institutional scenarios do not coincide.

The model is subject to be extended in several directions. On the one hand, the model should be extended to incorporate regional spillovers of pollution. This assumption increases the interregional links of environmental policy, which may have significative consequences on fiscal competition and plant location (reference to be introduced). On the other hand, a future extension of the model should incorporate a dynamics as a crucial factor determining the power of each government in the taxation game (reference to be incorporated).

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Figure 1. Non cooperative equilibrium when goods are substitutes

		B	
		0	1
A	0	**(A,B)** **(B,A)**	(A,A)
	1	(B,B)	**(A,B)** **(B,A)**

(a) $\overline{P} < 4.62$

		B	
		0	1
A	0	**(A,B)** **(B,A)**	(A,A)
	1	(B,B)	(A,B) (B,A)

(b) $\overline{P} > 4.62$

Figure 2. Equilibrium tax policies when goods are complements

		B		
		0		1
A	0	**(*A*,*A*)**	↔	**(*A*,*A*)**
		↑		↑
	1	(*B*,*B*)	←	(*A*,*A*)

Case (a)

		B		
		0		1
A	0	**(*B*,*B*)**	←	(*A*,*A*)
		↕		↑
	1	**(*B*,*B*)**	←	(*B*,*B*)

Case (b)

		B		
		0		1
A	0	**(*A*,*A*)**	↔	**(*A*,*A*)**
		↑		↑
	1	(*B*,*B*)	←	(*B*,*B*)

Case (c)

		B		
		0		1
A	0	**(*B*,*B*)**	←	(*A*,*A*)
		↕		↑
	1	**(*B*,*B*)**	←	(*A*,*A*)

Case (d)

Figure 3. Non cooperative (bold) versus cooperative (italic)

		B	
		0	1
A	0	**(A,B)** **(B,A)**	(A,A)
	1	(B,B)	***(A,B)*** ***(B,A)***

(a) $\overline{P} < 4.62$

		B	
		0	1
A	0	**(A,B)** **(B,A)**	(A,A)
	1	(B,B)	*(A,B)* *(B,A)*

(b) $\overline{P} > 4.62$

Figure 4. Non cooperative (bold) versus cooperative (italic)

		B	
		0	1
A	0	***(A,A)***	***(A,A)***
		(B,B)	(A,A)
	1		

Case (a)

		B	
		0	1
A	0	***(B,B)***	*(A,A)*
		(B,B)	(B,B)
	1		

Case (b)

		B	
		0	1
A	0	***(A,A)***	***(A,A)***
		(B,B)	(B,B)
	1		

Case (c)

		B	
		0	1
A	0	***(B,B)***	*(A,A)*
		(B,B)	(A,A)
	1		

Case (d)