Partial cross-ownership and strategic environmental policy

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ABSTRACT

This paper analyzes the effect that passive investment in rival firms has on the setting of cooperative and non-cooperative environmental taxes. We consider two firms located in different countries, one of which owns a stake in its rival. We show that partial cross-ownership affects the taxes set by the countries in the cooperative and non-cooperative cases. Depending on the stake that one firm has in its rival we show that cooperative taxes may be higher or lower than non-cooperative taxes. Moreover, for intermediate values of the stake, the non-cooperative tax is higher in one country and lower in the other than the cooperative tax.

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1. Introduction

There are many cases in which firms acquire a stake in their rivals that gives them a share in the profit but not in the decision making of those rivals (see Gilo et *al*., 2006).[1] These passive investments affect the production and thus the pollutant emissions of the firms. As a result, partial cross-ownership affects the strategic environmental policy of governments. However, it is generally assumed in literature on the environment that each firm is owned by a different shareholder (see, for example, Ulph, 1996; Duval and Hamilton, 2002). This paper examines the setting of cooperative and non-cooperative environmental taxes set by governments when there is cross-participation at ownership level.

The determination of optimal environmental taxes has received considerable attention in the economic literature analyzing the environment. Pigouvian taxation is regarded as a benchmark according to which under perfect competition the optimal environmental tax is equal to the marginal environmental cost. However, as markets are not perfectly competitive it is of general interest to analyze optimal environmental taxes under imperfect competition.[2]

The problem of optimal environmental taxation considering a single market and imperfectly competitive firms was first analyzed in Buchanan (1969) and then in Barnett (1980). They show that for an externality produced by a monopolist, the optimal tax is lower than the marginal environmental cost. The optimal tax consists of two parts: a Pigouvian tax (i.e. the marginal environmental cost), and a correction part due to the market power of the monopolist firm. This analysis has been extended to consider an oligopoly market.[3]

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[1] For an explanation of why partial ownership arrangements are formed see Alley (1997). One of the reasons is that they alter the degree of competition in the industry (see, for example, Reynolds and Snapp, 1986; Farrell and Shapiro, 1990; Malueg, 1992; Ono et *al*., 2004; Gilo et *al*. 2006).

[2] See Requate (2006) for an excellent survey on this issue.

[3] In this regard see Simpson (1995), Katsoulacos and Xepapadeas (1995) and Carlsson (2000). They show that the optimal tax is not necessarily lower than the marginal environmental cost. Optimal environmental policies have also been analyzed assuming that firms produce differentiated products (see, for example, Katsoulacos and Xepapadeas, 1996; Lange and Requate, 1999; and Fujiwara, 2009), and that private firms compete with public firms (see Bárcena-Ruiz and Garzón, 2006).

The literature on the environment has also analyzed strategic environmental policy when there is international trade and firms are imperfectly competitive. Considering Cournot competition, in this framework Barrett (1994) and Ulph (1996) show that when the firms located in each country are domestic-owned, national governments set emission standards such that the marginal cost of abatement is lower than the marginal damage caused by polluting emissions. Conrad (1993) assumes that firms sell in a third country's market and shows that non-cooperative emission tax rates are lower than the tax that would be set by the governments if they coordinated their policies so as to maximize the joint welfare of the countries. The same result is obtained by Conrad (1996a) and Kennedy (1994) assuming that firms sells their products in a single market (that includes domestic consumers) and assuming transboundary pollution.[4]

The design of environmental policy with imperfect competitive polluting industries has been extended to consider other factors that influence that policy. In this regard, Bárcena-Ruiz (2006) analyzes whether governments prefer to be leaders or followers in environmental policies when transboundary pollution is assumed.[5] He shows that in the cooperative equilibrium taxes are higher than in the non-cooperative equilibrium independently of whether they are set sequentially or simultaneously. In the non-cooperative equilibrium, both countries set the same tax under simultaneous decisions; however, under sequential decisions the leader government in taxes sets a higher (lower) tax than the follower if transboundary spillovers are low (high) enough.

[4] This analysis has been extended to consider Bertrand competition (see, for example, Conrad, 1996b; and Eerola, 2004). Another branch of the literature studies the interaction between strategic environmental policy and endogenous location of polluting firms (see, for example, Rauscher, 1995; Markusen, 1997; and Bárcena-Ruiz and Garzón, 2003).

[5] This paper shows that whether governments prefer to be leaders or followers in taxes depends on the degree to which environmental pollution spills over to trading partners. When this overspill is low (high) enough, taxes are strategic complements (substitutes) and governments set taxes sequentially (simultaneously).

Duval and Hamilton (2002) extend the analysis of strategic environmental policy to consider market conditions characterized by various forms of international asymmetry.[6] They find that in the cooperative equilibrium the optimal tax under asymmetric-cost oligopoly does not involve taxes harmonized between countries (i.e. governments set different taxes); for other forms of asymmetry, policy harmonization is optimal. In the case of unbalanced trade (i.e. domestic consumption does not equal domestic production), a net exporting country has an incentive to raise its tax because a portion of the tax is shifted onto prices, where it disproportionately affects foreign consumers. For a general distribution of the global consumer base, they find that the motivation of the domestic country to capture oligopoly rent for its firms is countervailed by the desire of the regulator to shift the burden of the tax onto foreign consumers. As a result, a net exporting (importing) country has an incentive to set higher (lower) environmental taxes than would be efficient under cooperation.[7]

In this paper we consider partial cross-ownership, which means a factor that influences the environmental policy of governments which is different from that in the papers cited above. Under partial cross-ownership one firm (firm *f*) owns a stake in its rival (firm *r*), but the control of each firm is exerted by its main shareholder. In order to simplify the analysis we assume that each firm owns the same percentage stake in its rival. Firms are owned by investors from the country in which they are located: firm *i* is owned by investors from country *i* ($i = r, f$). We consider that environmental damage is global and thus there are environmental spillovers. This means that the greater the environmental spillovers are the greater the fraction of pollution from one country that spills over to the other country will be. The purpose of this paper is to investigate how partial cross-ownership affects the setting of cooperative and non-cooperative environmental taxes by governments.

[6] Asymmetries are expressed in terms of consumption (different number of consumers in each country), production (different numbers of firms in each country or different production costs), and environmental damage (various forms of transboundary pollution).

[7] In the case of balanced trade and no transboundary pollution, the optimal cooperative and non-cooperative taxes coincide. However, with transboundary pollution the net importer of pollution sets a lower tax than the net exporter as an incentive to increase domestic pollution.

The issue that we analyze in this paper can be illustrated by taking the automobile industry as an example. In this industry there are examples of partial cross-ownership of rivals, e.g. the French firm Renault has formed a partnership with the Japanese firm Nissan. Renault currently holds a 44.3% equity stake in Nissan Motor and Nissan Motor owns a 15% stake in Renault (see www.renault.com).[8] Moreover, in advanced countries governments set environmental taxes to get firms to internalize the damage generated by their pollutant emissions (see, for example, European Environmental Agency, 2007). We set our model in this context.

We consider first that countries set the environmental taxes that maximize the joint welfare of the two countries (cooperative taxes).[9] Partial cross-ownership of firms reduces their productions and emissions, thus providing an incentive for countries to decrease the tax paid by the firms to avoid an excessive reduction of production. As a result, firms pay lower taxes than when there is no partial cross-participation. It should be noted that as environmental taxes maximize the joint welfare of the two countries, it is taken into account when setting environmental taxes that the pollutant emissions of each country also damage the other country. Thus, environmental spillovers increase cooperative taxes and decrease marginal environmental damage. This implies that if environmental spillovers are great enough, the marginal environmental damage is lower than the tax.

In the non-cooperative case, given that there is strategic interaction between governments when setting environmental taxes, the following effects are present when environmental damage is local: first, the rent capture effect, which lowers equilibrium taxes as each country attempts to gain a competitive advantage over the other; second, the pollution-shifting effect, which raises equilibrium taxes as each country attempts to

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[8] Another example is the partial acquisition of Wilkinson by Gillette: Gillette acquired 22.9% of the nonvoting stock and approximately 13.6% of the debt of Wilkinson Sword, one of its largest rivals (see Gilo et *al*., 2006); the former is from the U.S.A while the latter is from the U.K.

[9] As firms have market power and their production processes damage the environment, when there is no cross-ownership it is well known (see Barnett, 1980) that a tax on pollution emissions reduces the environmental damage caused by firms but also causes them to reduce their production further (from already sub-optimal levels). Therefore, environmental taxes are below marginal environmental damage to avoid an excessive reduction of production by firms.

transfer production and its associated pollution to the other. Both the above effects are influenced by partial cross-ownership. On the one hand, partial cross-ownership reduces market competition, increasing the profits of firms. This means that the incentive to reduce taxes to capture rents from foreigners, the rent capture effect, is weakened. On the other hand, firms produce and pollute less than when there is no partial cross-ownership. As a result, the incentive to increase taxes to move production and its associated pollution to the other country, the pollution-shifting effect, is weakened. Thus, countries set a lower tax than when there is no partial cross-ownership since the rent capture effect dominates the pollution-shifting effect. When there are transboundary spillovers the incentive to transfer production and thus pollution to the other country is weaker than when environmental damage is purely local. Therefore, transboundary spillovers weaken the incentive of each government to raise the tax so as to send production abroad.

We next compare cooperative and non-cooperative taxes. Given that the rent capture effect dominates the polluting-shifting effect, when there is neither partial cross-ownership nor environmental damage non-cooperative taxes are lower than cooperative taxes (see Kennedy, 1994). However, this result changes under partial cross-ownership (assuming that environmental damage is purely local). In each country the tax set in the cooperative and non cooperative cases decreases with the stake that its domestic firm has in the foreign firm. However, the cooperative tax decreases more than the non-cooperative tax with that stake since in the latter case the pollution-shifting effect dominates, which weakens the incentive to reduce the tax. As a result, the non-cooperative tax is higher than the cooperative tax when the stake is high enough. When there are transboundary spillovers the incentive to transfer production and pollution to the other country is weaker. Therefore, transboundary spillovers weaken the incentive of the governments to raise the tax so as to send production abroad. As a result, when transboundary spillovers are great enough the taxes set by the governments are lower in the non-cooperative case than in the cooperative one. This means that when transboundary spillovers are great enough the cross-ownership effect is weak enough to raise the taxes set by the governments above cooperative taxes.[10]

The rest of the paper is organized as follows. Section 2 presents the model. Sections 3 and 4 analyze the environmental taxes set by governments in the cooperative and non-cooperative cases respectively and Section 5 draws conclusions.

2. The model

We consider a world market comprising two countries denoted by 1 and 2. There is one firm located in each country and the two firms produce a homogeneous good whose production process damages the environment. Firm i is located in country i, i=1, 2. There is free trade and the firms sell their products in the world market. There are no transportation costs, and there is no possibility of discriminating between consumers from different countries.

We assume that there is bilateral partial cross-ownership. Firm i owns α_i percent of the stock of firm j, and the latter firm owns α_j percent of the stock of its rival, α_i, α_j <1/2 ($i \neq j$; i, j=1, 2); thus, each firm has a share in its rival's decision making. In order to simplify the analysis we assume that $\alpha_i=\alpha_j=\alpha$. As firm i owns α percent of the stock of firm j and (1-α) percent of its own stock, it chooses the output level q_i that maximizes $(1-\alpha)\pi_i+\alpha\pi_j$. We assume that investors from country i own firm i and thus the producer surplus in this country is: $PS_i = (1-\alpha)\pi_i+\alpha\,\pi_j$, $i \neq j$; i, j=1, 2.

The inverse demand function of country i is given by: $p = A - 2y_i$, i =1, 2, where p is the world market price of the good and y_i is the amount of the good sold in country i.

[10] It can be shown that in the asymmetric case in which each firm holds a different percentage of the stock of its rival (assuming that firm f has a lower percentage of the stock of its rival than firm r), both countries set a higher tax in the non-cooperative case if environmental spillovers are low enough, both countries set a lower tax in the non-cooperative case if environmental spillovers are high enough and, finally, if environmental spillovers take an intermediate value, country f (r) sets a higher (lower) tax in the non-cooperative case.

Therefore, demand from the world market is given by the following inverse demand function: $p = A - q_1 - q_2$, where $y_1+y_2 = q_1+q_2$. Let q_i denote the amount of the good that firm i sells on the world market. The consumer surplus in country i is given by:

$$CS_i = (y_i)^2,\ i = 1, 2. \qquad (1)$$

There is a pollutant associated with the production of the good. Specifically, each unit of output causes one unit of pollutant emissions. However, firms have technology available for abating this pollution. Firms can abate emissions, and so we denote by a_i the abatement level of firm i. As a result, the total pollutant emission level of firm i, e_i, is: $e_i = q_i - a_i$. Abating emissions entails a positive cost, and the total cost of pollution abatement is given by: $C(a_i) = k\,(a_i)^2$.

Firm i pays an environmental tax, t_i, per unit of pollution emitted. This tax is set by government i. Therefore, the total taxes collected by government i, are $T_i = t_i\, e_i$. Given that each firm has to pay an environmental tax per unit of pollution emitted, the profit of firm i is:

$$\pi_i = (A - q_i - q_j - c)\, q_i - t_i\,(q_i - a_i) - k\,(a_i)^2,\ i \neq j;\ i, j = 1, 2. \qquad (2)$$

Firms produce a homogeneous good whose production process causes bilateral transboundary pollution. The environmental damage in country i is given by:[11]

$$D_i = \lambda\,(e_i + s e_j)^2,\ i = 1, 2, \qquad (3)$$

where parameter λ measures the valuation of the environment by government i. Parameter s measures the degree to which environmental pollution spills over to trading partners (transboundary spillovers). Transboundary spillovers increase with parameter s. Parameter

[11] The literature on the environment usually assumes that environmental damage is a convex function of the total pollution level. See, for example, Falk and Mendelson (1993), Van der Ploeg and Zeeuw (1992), Ulph (1996), and Bárcena-Ruiz (2006).

s varies between 0 and 1: s=0 means that damage is purely local and s=1 means that emissions cause the same damage in the two countries.

The social welfare function considered by government i comprises the consumer and producer surpluses in country i (denoted by CS_i and PS_i, respectively) the total taxes collected by government i (T_i) and the environmental damage caused by the production process in country i (D_i). Specifically, the social welfare function for country i is:

$$W_i = CS_i + PS_i + T_i - D_i,\ i=1, 2. \tag{4}$$

We consider the following timing. In the first stage environmental taxes are set simultaneously. In the second stage the firms simultaneously choose their output and pollution abatement levels. We solve the game by backward induction from the last stage of the game to obtain a subgame perfect Nash equilibrium. For the sake of simplicity we assume that k=2 and λ=2. The main results hold for values of parameters k and λ other than 2.

3. Optimal environmental taxes in the cooperative case.

Next we consider the cooperative policy outcome, denoted by superscript C. In that case, the two countries set the taxes that maximize their joint welfare. In the second stage, firms simultaneously choose the output and abatement levels that maximize their objective functions. Firm i chooses the output level, q_i, and the abatement level, a_i, that maximize $(1-\alpha)\pi_i+\alpha\pi_j$. Solving this, we obtain the equilibrium output and abatement levels as a function of environmental taxes:

$$q_i = \frac{(1-\alpha)((A-c)(1-2\alpha)+t_j-2t_i(1-\alpha))}{3-8\alpha+4\alpha^2},\ a_i = \frac{t_i}{4},\ i\neq j;\ i, j=1, 2. \tag{5}$$

From expression (5) we obtain that the output level of firm i decreases with parameter α, for a given value of t_i and t_j. When firm i chooses output level q_i it takes into account how it affects the profit of its rival. Thus, the higher the value of parameter α the lower the output level of firm i, q_i, and the higher the output level of firm j, q_j. As the effect of parameter α on the own output dominates, the output of the industry decreases with parameter α, which means that cross-ownership reduces market competition. Expression (5) also shows that $a_i = t_i/4$, which is just the usual condition that firm *i* abates pollution to the point where the marginal abatement cost equals the tax.

Next we solve the first stage of the game. In this stage the taxes t_1 and t_2 are chosen such that the joint welfare of the two countries, W_1+W_2, is maximized. Solving this, we obtain the environmental tax set by each country:[12]

$$t_i^C = \frac{4(A-c)(1-\alpha)(6(1-\alpha)+s(2+s)(7-6\alpha))}{2(33-56\alpha+24\alpha^2)+s(2+s)(7-6\alpha)^2}, \; i = 1, 2. \tag{6}$$

Let $s_m = \dfrac{3(1-\alpha)-\sqrt{23-30\alpha+9\alpha^2}}{6\alpha-7}$, $0<s_m<1$. From (6), we obtain the following result.

Proposition 1. *When environmental taxes maximize the joint welfare of the two countries:*

i) $\dfrac{\partial t_i^C}{\partial \alpha}<0$, $\dfrac{\partial t_i^C}{\partial s}>0$, $\dfrac{\partial MED_i^C}{\partial \alpha}<0$, $\dfrac{\partial MED_i^C}{\partial s}<0$, $MED_i^C>t_i^C$ *if and only if* $s<s_m$;

ii) $\dfrac{\partial D_i^C}{\partial \alpha}<0$, $\dfrac{\partial D_i^C}{\partial s}<0$, $\dfrac{\partial W_i^C}{\partial \alpha}<0$, $\dfrac{\partial W_i^C}{\partial s}<0$.

Proof. See Appendix.

Given that in the cooperative case environmental taxes maximize the joint welfare of the two countries these taxes are chosen for efficiency reasons. We consider imperfectly competitive firms whose production process generates pollution that damages the

[12] It can be seen that environmental taxes are strategic complements ($\partial t_i/\partial t_j>0$) if parameter *s* is low enough for a given value of parameter α; in that case, if the tax set in one country rises (falls) the tax set in the other country also rises (falls). For the remaining values of the parameters, environmental taxes are strategic substitutes ($\partial t_i/\partial t_j<0$); in that case, if the tax set in one country rises (falls) the tax set in the other country falls (rises).

environment, so when environmental damage is local (s=0) and there is no partial cross-ownership (α=0), two effects have to be taken into account (see Barnett, 1980) to explain the result shown in this proposition: first, the underproduction associated with the exercise of the market power of firms (the underproduction effect); and second, the fact that in the absence of environmental policies polluting firms do not internalize the environmental damage caused by their pollutant emissions (the pollution-internalization effect). Thus, a tax on pollutant emissions reduces the environmental damage caused by firms but also causes firms to reduce their production further (from already sub-optimal levels). Therefore, the underproduction effect dominates and thus environmental taxes are set below marginal environmental damage (see Figure 1) to avoid an excessive reduction in production by firms.

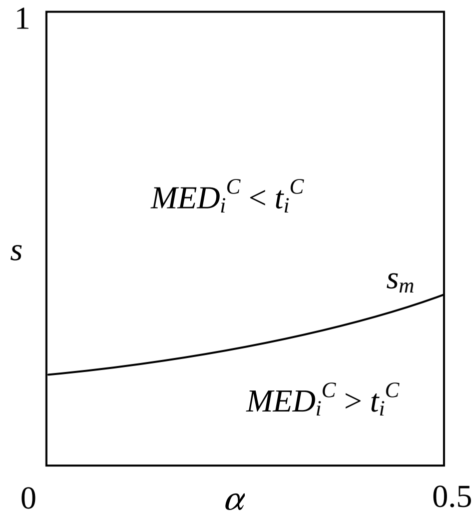

Fig. 1. Comparison of taxes and *MED* in the cooperative case.

If we now assume that there is partial cross-ownership (when s=0), an additional effect arises (the cross-ownership effect) that influences the effects mentioned above. First, for given taxes, cross-ownership reduces the output of industry and thus market competition. As a result, the underproduction effect (and thus the incentive of governments to lower taxes) is strengthened. Secondly, for given taxes, as firm i owns α percent of the stock of its rival it reduces its own production and emissions with parameter α. As a result, cross-ownership weakens the incentive of the countries to increase the tax paid by firm i to get this firm to internalize the damage caused by its pollutant emissions. Therefore, the underproduction effect dominates and thus t_i^C and MED_i^C decrease with parameter α ($\partial t_i^C / \partial \alpha < 0$, $\partial MED_i^C / \partial \alpha < 0$). This means that the cross-ownership effect lowers cooperative equilibrium taxes. Environmental taxes are below marginal environmental damage (see Figure 1) to avoid an excessive reduction in production by firms.

Finally we also consider that there are transboundary spillovers (*s*>0). As environmental taxes maximize the joint welfare of the two countries, when setting environmental taxes it is taken into account that the environmental damage suffered by each country increases with transboundary spillovers. This means that t_i^C increases with parameter *s* ($\partial t_i^C / \partial s > 0$) and thus MED_i^C decreases with this parameter ($\partial MED_i^C / \partial s < 0$). This implies that if parameter *s* is great enough ($s>s_m$), the marginal environmental damage is lower than the tax; if parameter *s* is low enough the opposite result is obtained (see Figure 1).

The environmental damage suffered by country *i* decreases with both α and *s* ($\partial D_i^C / \partial \alpha < 0$, $\partial D_i^C / \partial s < 0$). The tax set in country *i* (and thus its abatement level) decreases with parameter α, which has less effect than the reduction in its output level, implying that its emission level and the environmental damage decrease with this parameter. Thus, environmental damage in the two countries is lower than when there is no partial cross-ownership. On the other hand, as the tax set in country *i* increases with parameter *s*, its emission level and the environmental damage decrease with this parameter.

The usual result obtained when there is partial cross ownership but there is no environmental damage is that passive investments between rivals might substantially lessen competition and thus social welfare (see Gilo et *al.*, 2006). This result is also obtained when we consider global environmental damage. Although environmental damage decreases with parameter α, as the consumer surplus in country *i* decreases also with this parameter social welfare decreases with parameter α ($\partial W_i^C / \partial \alpha < 0$). On the other hand, as the consumer surplus in country *i* decreases with parameter *s*, social welfare decreases with this parameter ($\partial W_i^C / \partial s < 0$).

4. Optimal environmental taxes in the non-cooperative case.

Next we consider the non-cooperative case, denoted by superscript *NC*. In the second stage, firms simultaneously choose the output and abatement levels that maximize their objective functions. Solving these problems we obtain expression (5). In the first stage of the game, governments simultaneously set the environmental taxes that maximize their social welfare functions, given by (4). Solving these problems we obtain the environmental tax set by each government:

$$t_i^{NC} = \frac{4(A-c)(1-\alpha)(9-16\alpha+2\alpha^2+4\alpha^3+s(7-20\alpha+12\alpha^2)-4s^2(1-\alpha))}{3(34-93\alpha+70\alpha^2-4\alpha^3-8\alpha^4)+s(7-6\alpha)((7-6\alpha)(1-2\alpha)-2s(1-\alpha))},\ i=1,2. \quad (7)$$

Let $s_t = (7 - 20\alpha + 12\alpha^2) / (8 - 8\alpha)$, and $s_n = (-154 + 545\alpha - 746\alpha^2 + 476\alpha^3 - 120\alpha^4 + (352216 - 2995948\alpha + 11511329\alpha^2 - 26379900\alpha^3 + 40055280\alpha^4 - 42243872\alpha^5 + 31426144\alpha^6 - 16313280\alpha^7 + 5657856\alpha^8 - 1182720\alpha^9 + 112896\alpha^{10})^{1/2}) / (4(125 - 446\alpha + 601\alpha^2 - 364\alpha^3 + 84\alpha^4))$. From (7) we obtain the following result.

Proposition 2. *In equilibrium:*

i) $\frac{\partial t_i^{NC}}{\partial \alpha} < 0$, $\frac{\partial t_i^{NC}}{\partial s} > 0$ *if and only if* $s<s_t$, $\frac{\partial MED_i^{NC}}{\partial \alpha} < 0$ *if and only if* $s<s_n$, $\frac{\partial MED_i^{NC}}{\partial s} < 0$, $MED_i^{NC} > t_i^{NC}$;

ii) $\frac{\partial D_i^{NC}}{\partial \alpha} < 0$ *if and only if* $s < s_n$, $\frac{\partial D_i^{NC}}{\partial s} > 0$.

Proof. See Appendix.

Given that there is strategic interaction between governments when setting environmental taxes, when there is neither partial cross-ownership nor transboundary spillovers (i.e. when $\alpha = s = 0$) the result obtained in this proposition is explained by two effects: first, the rent capture effect, which lowers equilibrium taxes as each country attempts to gain a competitive advantage over the other (a unilateral reduction in the domestic tax rate has the potential to raise net exports and so permits the capture of rent from foreigners); and second the pollution-shifting effect, which raises equilibrium taxes as each country attempts to transfer production and its associated pollution to the other country.

If we now consider partial cross-ownership (α>0) when there are no transboundary spillovers (*s*=0), an additional effect -the cross-ownership effect- arises that influences the two effects mentioned above. First, as partial cross-ownership reduces market competition the profit of firm *i* increases with parameter α. This means that the incentive to reduce taxes to capture rents from foreigners (the rent capture effect) is weakened in country *i*. Second, for given taxes, firm *i* produces and pollutes less than when there is no cross-ownership. This means that the incentive to increase taxes to send production and thus its associated pollution to the other country (the pollution-shifting effect) is weakened in country *i*. The rent capture effect dominates the pollution-shifting effect in country *i*, implying that when *s*=0 its tax and the marginal environmental damage decrease with parameter α ($\partial t_i^{NC}/\partial\alpha<0$ and $\partial MED_i^{NC}/\partial\alpha<0$).

Finally, we also consider that there are transboundary spillovers (*s*>0). In that case, the greater the value of parameter *s* is the greater the fraction of pollution from country *i* that spills over to country *j* will be. As a result, the incentive to transfer production (and thus pollution) to the other country is weaker than when environmental damage is purely local. This means that transboundary spillovers weaken the incentive of each government to raise the tax so as to send production abroad since the greater the value of parameter *s* is, the weaker the pollution-shifting effect is. As a result, $\partial t_i^{NC}/\partial s>0$ if and only if $s<s_t$.[13] However, $\partial t_i^{NC}/\partial\alpha<0$ for all *s* since cross-ownership reduces market competition. But as t_i^{NC} decreases with parameter *s* if this parameter is high enough ($s>s_n$), it is obtained that marginal environmental damage decreases with parameter α ($\partial MED_i^{NC}/\partial\alpha<0$). By contrast, the marginal environmental damage increases strictly with parameter *s* ($\partial MED_i^{NC}/\partial s>0$) since governments do not take into account environmental spillovers when setting their taxes. Finally, and in contrast with the result obtained in the cooperative

[13] It should be noted that in the cooperative case the cooperative tax increases strictly with parameter *s*.

case, marginal environmental damage in the non cooperative case is greater than the tax for all s ($MED_i^{NC} > t_i^{NC}$).

In contrast to the result obtained in the cooperative case, environmental damage increases with parameter s since neither country takes into account that the polluting emissions of its firms also damage the other country. The environmental damage suffered by the two countries decreases with parameter α if parameter s is low enough ($s<s_n$) since marginal environmental damage decreases with this parameter. Therefore, partial cross-ownership reduces environmental damage in both countries.

Social welfare in country i may increase or decrease with parameter α (see Figure 2).[14] Specifically, social welfare increases with this parameter if α is low enough and s takes an intermediate value; in that case, market competition and environmental damage decrease with parameter α but as cross-ownership is low enough the reduction in environmental damage has a greater effect on social welfare. For the remaining values of the parameters social welfare decreases with parameter α (as, for example, when damage is local). Social welfare strictly decreases with parameter s.

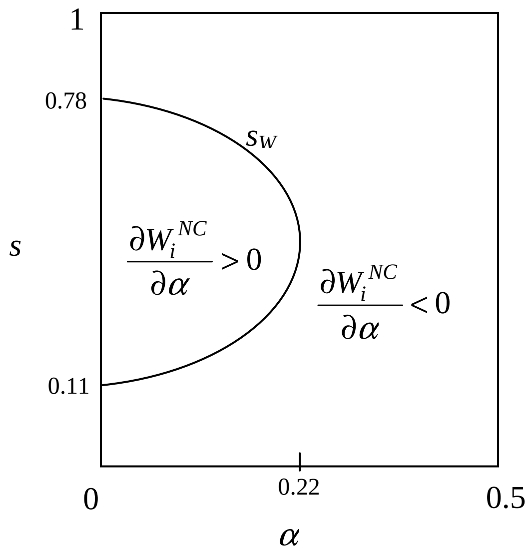

Fig. 2 Variation of social welfare with parameter α.

[14] It is very complex to analyze how social welfare varies with parameter α (see Appendix), so we made a simulation using Mathematica to analyze it for different parameter values.

We next compare the result obtained when governments set taxes cooperatively with that obtained when governments set taxes non-cooperatively. This result is illustrated in Figure 3. Let $s^{*}= (-21 + 46\alpha - 24\alpha^2 + (359 - 860\alpha - 224\alpha^2 + 2098\alpha^3 - 1872\alpha^4 + 504\alpha^5)^{1/2}) / (41 - 85\alpha + 42\alpha^2)$.

Proposition 3. *In equilibrium:* $t_i^{NC} > t_i^{C}$ *and* $D_i^{NC} < D_i^{C}$ *if and only if* $s<s^{*}$, i=1, 2.

Proof. See Appendix.

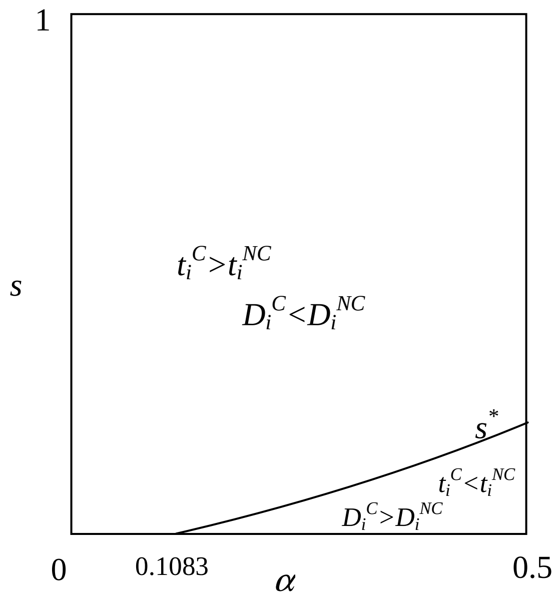

Fig. 3. Comparison of environmental taxes.

When each firm has a single owner (α=0) and environmental damage is local (s=0) there are neither cross-ownership effect nor transboundary spillovers. Thus, the rent capture effect dominates in the two countries, implying that equilibrium non cooperative taxes are lower than the taxes set in the cooperative case ($t_i^{NC} < t_i^{C}$).

When there is cross-ownership ($\alpha > 0$) and environmental damage is local (s=0), both t_i^{C} and t_i^{NC} decrease with parameter α. However, t_i^{C} decreases more than t_i^{NC} with parameter α since in the non-cooperative case the pollution-shifting effect dominates the rent capture effect, which weakens the incentive to reduce the tax. As a result, in this case t_i^{NC} is greater than t_i^{C} if parameter α is greater than 0.1083 (see Figure 3).

When we also consider that there are transboundary spillovers ($s > 0$) the incentive to transfer production and pollution to the other country is weaker. Thus, the greater the value of parameter s is, the weaker the pollution-shifting effect is. Therefore, transboundary spillovers weaken the incentive of the governments to raise the tax so as to send production abroad. As a result, when parameter s is great enough ($s > s^*$) the taxes set by governments are lower in the non-cooperative case than in the cooperative one. This means that when transboundary spillovers are great enough the cross-ownership effect is weak enough to raise the taxes set by the governments above cooperative taxes.[15]

As the taxes set in both countries are higher in the cooperative case than in the non-cooperative case when parameter s is low enough ($s < s^*$), environmental damage is lower in the former case. When parameter s is great enough, the opposite result is obtained.

6. Conclusion

There are many cases in which firms acquire a stake in their rivals that gives them a share in the profits but not in the decision making of those rivals. These passive investments affect the production and thus the pollutant emissions of the firms. As a result, partial cross-ownership affects the strategic environmental policy of governments. This issue has not been examined by the literature that analyzes the environmental policy of governments. Thus, this paper examines the setting of cooperative and non-cooperative environmental taxes by government when there is partial cross-ownership.

The design of environmental policy with imperfect competitive polluting industries has been analyzed considering different types of asymmetries between countries: sequential decisions on environmental taxes and various forms of international asymmetry. In this paper we consider a different asymmetry between governments. We assume that each

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[15] s^* increases with parameter α since t_i^C decreases more than t_i^{NC} with this parameter.

firm owns a stake in its rival and that firms are owned by investors from the country in which they are located.

When countries set the environmental taxes that maximize the joint welfare of the two countries we find that equilibrium taxes are lower than when there is no partial cross-participation. This result is also obtained in the non-cooperative case. However, the effects that explain these results differ from one case to the other, since in the cooperative case taxes are chosen for reasons of efficiency while in the non-cooperative case they are chosen for strategic reasons. A comparison of cooperative and non-cooperative taxes reveals that if the stake that each firm has in its rival is great enough both countries set a lower tax in the non-cooperative case. If that stake is low enough, both countries set a higher tax in the cooperative case.

Appendix

Proof of proposition 1

Let $K = 1/(2(33-56\alpha+24\alpha^2)+s(2+s)(7-6\alpha)^2)$. From (6):

$$q_i^C = K(A-c)(2+2s+s^2)(1-\alpha)(7-6\alpha),\; a_i^C = t_i^C/4,$$

$$e_i^C = q_i^C - a_i^C = 2K(A-c)(1-\alpha)(4-3\alpha),$$

$$D_i^C = 8K^2(A-c)^2(1+s)^2(1-\alpha)^2(4-3\alpha)^2,$$

$$CS_i^C = K^2(A-c)^2(2+2s+s^2)^2(7-6\alpha)^2(1-\alpha)^2,$$

$$W_i^C = K(A-c)^2(2+2s+s^2)(1-\alpha)(4-3\alpha),$$

$$MED_i^C = 2(1+s)e_i^C = 8K(A-c)(1+s)(1-\alpha)(4-3\alpha).$$

As $0<\alpha<1/2$ and $0<s<1$, it can be shown that:

i) $$\frac{\partial t_i^C}{\partial \alpha} = -4K^2(A-c)(2+2s+s^2)(s(2+s)(7-6\alpha)^2+12(5-9\alpha+4\alpha^2)) < 0,$$

$$\frac{\partial t_i^C}{\partial s} = 16K^2(A-c)(1-s)(1-\alpha)(3-2\alpha)(4-3\alpha)(7-6\alpha)) > 0,$$

$$\frac{\partial MED_i^C}{\partial \alpha} = -8K^2(A-c)(2+4s+3s^2+s^3)(7-6\alpha) < 0,$$

$$\frac{\partial MED_i^C}{\partial s} = -8K^2 (A-c) (4-7\alpha+3\alpha^2) (s (2 + s)(7-6\alpha)^2 + 8 (4-7\alpha+3\alpha^2))<0,$$

$MED_i^C - t_i^C = 4K (A-c) (1-\alpha) (2 - 6s(1 - \alpha) - s^2(7 - 6\alpha)) > 0$ if and only if $s < s^m$;

ii) $$\frac{\partial D_i^C}{\partial \alpha} = -16K^3(A-c)^2(1+s)^2(2+2s+s^2)(1-\alpha)(4-3\alpha)(7-6\alpha) < 0,$$

$$\frac{\partial D_i^C}{\partial s} = -16K^3(A-c)^2(1+s)(1-\alpha)^2(4-3\alpha)^2(s(2+s)(7-6\alpha)+8(4-7\alpha+3\alpha^2)) < 0,$$

$$\frac{\partial CS_i^C}{\partial \alpha} = -2K^3 (A-c)^2 (2+2s+s^2)^2 (7-13\alpha+6\alpha^2) (74-120\alpha+48\alpha^2 + s(2+s)(7-6\alpha)^2)) < 0,$$

$$\frac{\partial CS_i^C}{\partial s} = -32K^3 (A - c)^2 (1 + s) (2 + 2s + s^2) (7 - 6\alpha)^2 (1 - \alpha)^3 (4 - 3\alpha)<0,$$

$$\frac{\partial W_i^C}{\partial \alpha} = -K^2(A-c)^2(2+2s+s^2)^2(7-6\alpha) < 0,$$

$$\frac{\partial W_i^C}{\partial s} = -16K^2(A-c)^2(1+s)(4-7\alpha+3\alpha^2)^2 < 0,$$

Non-cooperative taxes

Let $H = 1 / (3 (-34 + 93\alpha - 70\alpha^2 + 4\alpha^3 + 8\alpha^4) - s (7 - 6\alpha) ((7 - 6\alpha) (1 - 2\alpha) + 4s (1 - \alpha))$. From (7) we obtain:

$a_i^{NC} = t_i^{NC}/4$, $q_i^{NC} = H (A-c) (1-\alpha) (-22 + 45\alpha - 16\alpha^2 - 4\alpha^3 - s (7 - 20\alpha + 12\alpha^2) + 4s^2 (1-\alpha))$,

$MED_i^{NC} = (4 H (A - c) (1 + s) (-13 + 42\alpha - 43\alpha^2 + 14\alpha^3))$,

$D_i^{NC} = 2H^2(A-c)^2(1+s)^2(13-42\alpha+43\alpha^2-14\alpha^3)^2$,

$W_i^{NC} = H^2 (A-c)^2 (-1+\alpha) (-1260 + 5680\alpha - 9020\alpha^2 + 5175\alpha^3 + 656\alpha^4 - 1608\alpha^5 + 320\alpha^6 + 48\alpha^7 + 16s^4 (1-\alpha)^2 (-4+3\alpha) + 8s^3 (28 - 129\alpha + 209\alpha^2 - 144\alpha^3 + 36\alpha^4) + s^2 (846 - 3251\alpha + 4366\alpha^2 - 2258\alpha^3 + 160\alpha^4 + 136\alpha^5) + 2s (-278 + 1636\alpha - 3451\alpha^2 + 3122\alpha^3 - 928\alpha^4 - 248\alpha^5 + 144\alpha^6))$.

Proof of proposition 2

Let $s_t = (7 - 20\alpha + 12\alpha^2)/(8 - 8\alpha)$, $s_n = (-154 + 545\alpha - 746\alpha^2 + 476\alpha^3 - 120\alpha^4 + (352216 - 2995948\alpha + 11511329\alpha^2 - 26379900\alpha^3 + 40055280\alpha^4 - 42243872\alpha^5 + 31426144\alpha^6 - 16313280\alpha^7 + 5657856\alpha^8 - 1182720\alpha^9 + 112896\alpha^{10})^{1/2} / (4\ (125 - 446\alpha + 601\alpha^2 - 364\alpha^3 + 84\alpha^4))$. As $0<\alpha<1/2$ and $0<s<1$, it can be shown that:

i) $\frac{\partial t_i^{NC}}{\partial \alpha} < 0$, $\frac{\partial t_i^{NC}}{\partial s} < 0$ if and only if $s>s_t$, $\frac{\partial MED_i^{NC}}{\partial \alpha} < 0$ if and only if $s<s_n$, $\frac{\partial MED_i^{NC}}{\partial s}<0$, and $MED_i^{NC} - t_i^{NC} = 4H\,(A - c)\,(1 - \alpha)\,(-4 + 13\alpha - 12\alpha^2 + 4\alpha^3 - s\,(6 - 9\alpha + 2\alpha^2) - 4s^2(1-\alpha)) > 0$;

ii) $\frac{\partial D_i^{NC}}{\partial \alpha} < 0$ if and only if $s < s_n$, $\frac{\partial D_i^{NC}}{\partial s} > 0$;

iii) $\frac{\partial W_i^{NC}}{\partial s} < 0$, $\frac{\partial W_i^{NC}}{\partial \alpha} = H^3\,(A - c)^2\,(- 64s^6\,(1 - \alpha)^3 + 48s^5\,(1 - \alpha)^2\,(7 - 20\alpha + 12\alpha^2) + s^3\,(54711 - 359180\alpha + 1013724\alpha^2 - 1593336\alpha^3 + 1503088\alpha^4 - 848448\alpha^5 + 264384\alpha^6 - 34944\alpha^7) - 4s^4\,(-8873 + 56625\alpha - 154896\alpha^2 + 235804\alpha^3 - 215820\alpha^4 + 118632\alpha^5 - 36176\alpha^6 + 4704\alpha^7) + s^2\,(-23918 + 194865\alpha - 728088\alpha^2 + 1639680\alpha^3 - 2435756\alpha^4 + 2445624\alpha^5 - 1639936\alpha^6 + 702080\alpha^7 - 173376\alpha^8 + 18816\alpha^9) + s\,(-38372 + 310196\alpha - 1133931\alpha^2 + 2450260\alpha^3 - 3431652\alpha^4 + 3218784\alpha^5 - 2021328\alpha^6 + 822080\alpha^7 - 197568\alpha^8 + 21504\alpha^9) - 3\,(-1600 + 1380\alpha + 39750\alpha^2 - 181441\alpha^3 + 384556\alpha^4 - 489708\alpha^5 + 408784\alpha^6 - 229680\alpha^7 + 84672\alpha^8 - 18496\alpha^9 + 1792\alpha^{10}))$. Let s_W the value of parameter s such that the above expression is zero.

Proof of proposition 3

Comparing the taxes and the environmental damage in the cooperative and non cooperative cases we obtain:

i) $t_i^{NC} - t_i^{C} = 4\,K\,H\,(A - c)\,(3 - 2\alpha)^2\,(\alpha - 1)\,(-2 + 22\alpha - 34\alpha^2 + 12\alpha^3 + s\,(-42 + 92\alpha - 48\alpha^2) + s^2\,(-41 + 85\alpha - 42\,\alpha^2)) > 0$ if and only if $s < s^*$.

ii) $D_i^{NC} - D_i^{C} = 2K^2 H^2 (A - c)^2 (1 + s)^2 (1 - \alpha)^2 (3 - 2\alpha) (7 - 6\alpha) (2 - 22\alpha + 34\alpha^2 - 12\alpha^3 + s^2 (41 - 85\alpha + 42\alpha^2) + s (42 - 92\alpha + 48\alpha^2)) (2s (7 - 6\alpha)^2 (17 - 40\alpha + 20\alpha^2) + s^2 (413 - 1929\alpha + 3086\alpha^2 - 2076\alpha^3 + 504\alpha^4) + 2 (837 - 3107\alpha + 4075\alpha^2 - 2158\alpha^3 + 276\alpha^4 + 72\alpha^5)) > 0$ if and only if $s < s^*$.

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