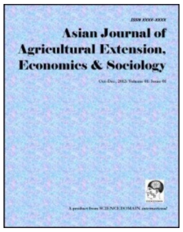

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Pollution and Commerce Control between Emerging Countries

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Authors' contributions

Author SSB handled the data and results presented in this paper. Author SCR, made contributions in the methodology and prepared the final draft of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

This work presents a mathematical model for reciprocal dumping and transboundary pollution, under a setting of oligopolistic competition. To control emissions, governments can establish two environmental regulation instruments: quotas and taxes. To do so, they calculate the optimal values for these variables and implement environmental policies, which aim to maximize the welfare function for both consumers and manufacturing companies and improve tax revenue and the social cost of polluting. With this model, we are able to conclude that when the social cost of polluting is high, governments should impose a quota for the level of pollution or a tax for contaminating. However, if the cost to abate pollution is high, the government may increase the pollution quota or reduce the tax.

Keywords: Optimaltax; optimalquota; reciprocal dumping; transboundary and pollution.

1. INTRODUCTION

The increasing worldwide demand of goods and services is one of the causes why companies pollute more. The dynamics of these economics that contribute to a surge of

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environmental contamination is a severe problem and adds directly or indirectly to desertification, loss of habitat, green-house effect, climate change, increase in the average level of oceans, decreased ozone layer, adverse health effects and a number of other negative repercussions in the global environment [1].

Therefore, if governments establish stricter controls to reduce emissions from industries, it can have the side effect of an increase in production costs and the price of goods, and a reduction in investment flows, job loss among others. Thus, governments must strategically weigh and promote a harmoniously economic development without undermining the environment.

Furthermore, there is abundant information regarding sustainably blending economic development and environmental policy instruments in developed countries.[1] But for developing countries, the literature is scarce. It is evident that there are significant differences between the two groups of countries.[1] For example, developing countries face greater difficulties to venture into global markets, they have weak productive infrastructure and financial resources, an increased pressure on natural resources, and their labor force is generally less specialized. These among other circumstances underscore how the costs and benefits of globalization are distributed differently [2]. Thus, this paper analyzes the implementation of environmental control policies among developing countries that trade with each other, a situation in which we can clearly include Mexico and other Latin American countries.

During the two past decades, there has been growing interest in the intra-industry trade, where countries export goods to each other, which are broadly similar in nature, or even identical [7]. Intra-industry trade may be defined as the two-way exchange of goods in which neither country seems to have a comparative advantage [8]. An interesting explanation of intra-industry trade (on which we will focus) was elaborated by [9]: the reciprocal dumping.[2]

The model presented for this work assumes the existence of reciprocal dumping, that is the bilateral trade of a homogeneous good between two countries (considering substantial amounts of agricultural and industrial goods). This type of trade happens when markets are segmented and there is price discrimination between producers in both countries. Hence companies –under the assumption of separate markets– make strategically business decisions [9]. As a result, firms often set a higher price in their domestic market than at the international market, thus fostering ideal conditions for trade, regardless of the differences in cost structure between the firms of both countries. Also, there are constant returns to scale [9]. In theory, reciprocal dumping can increase the competitiveness of companies, as it provides lower prices, and shrinks the number of monopolies or oligopolies, as they lose their power as similar goods from abroad are imported which is positive for consumers in both countries [9]. So, the reciprocal dumping model applies to common international trade situations in developing countries (especially Latin America countries), because these countries trade with each other similar or identical agricultural and industrial goods [10].

The model implements two environmental policy instruments widely used for environmental control: quotas and pollution taxes.[3] Quotas involve setting a permissible emission of pollutants, which, if overpassed, will be subject to penalties and/or fines are applied.

[1] *For example [3-6] among others.*

[2] *Well known literature on reciprocal dumping include [9,12,13] among others, and regarding intra-industry commerce we have [14-17] among others.*

[3] *For a detailed discussion on these environmental instruments see [6].*

Pollution taxes involve collecting certain amount of money per unit of pollution produced. The more the pollution, the higher the tax. For both cases, the government intends to effectively regulate the level of pollution generated by their production processes, and thus address this market failure. The model assumes that each firm generates emissions in their production processes, but also has the technology to bring them down. The fact that they pollute implies an underlying social cost which is measurable and for the companies responsible.

We assume the existence of transboundary pollution.[4]Transboundary pollution occurs when the pollution flows from one country across the territorial limits to another country. In this paper, transboundary pollution is bilateral: between the two countries that trade with each other, and the amount of pollution has a direct link to the levels of exports of those goods. Governments will try to control emissions on both domestic and foreign companies through the implementation of pollution taxes and quotas.[5]

Accordingly, the developed model in this work determines the quota and the optimal pollution tax for two small countries (if they have no market power in the international arena; [11] that trade with each other with a homogeneous good under conditions of oligopoly, reciprocal dumping and transboundary pollution.[6] From these values, we deducted a series of strategic environmental policies that aim to maximize welfare of the trading countries. Such welfare is represented by a mathematical function that includes producers, consumers, government and the environment.

The assumptions in the applied model to common international trade situations in developing countries (especially Latin American countries), which are not the focus of the extensive literature regarding developed countries or the ones that present a clear distinction between big and small countries. For instance, Mexico and Costa Rica trade with each other sugar, and apply a pollution quota to production companies; furthermore pollutants pas or cross between countries due to their geographical proximity. However neither country has market power to influence the world price, thus, they can be considered small countries [10].

The environmental policy results derived from the model are simple and intuitive: if the social cost of polluting is very high, then the government sets a zero pollution level quota to firms or establishes high taxes, therefore emissions tend to decrease. But if the pollution abatement costs are very high the government allows some reasonable amount of releases or affordable taxes to businesses in order to ensure their competitiveness in the international arena. If the marginal cost of pollution is greater than the cost of abatement, then applying the two instruments for environmental control have the same effect: pollution is reduced to the maximum level, that is, the government requires a zero pollution quota, or the companies decide on their own account not to emit pollutants.
This paper describes two similar models. One that considers an environmental control tool, pollution quotas, and another that uses pollution taxes. We include a proposition that relates both models and lastly conclusions are presented.

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[4]There are several studies regarding transboundary pollution and international commerce like [18-22] to name a few.
[5][22] developed a similar model in which they included another environmental policy instrument: countervailing duties. So the present work is a continuation regarding transboundary pollution research.
[6]Previous works that examine environmental controls in oligopolistic models including reciprocal dumping we have [10, 22-24]; among others.

2. POLLUTION QUOTAS MODEL

2.1 Specifications

Lets consider the trade of a homogeneous good between two countries: $L$and E, under conditions of reciprocal dumping. Country L produces the good for local consumption and export to country E. Therefore, the production function for any particular company in country L of the homogeneous good is:

$$X = X_L + X_E \tag{1}$$

Where,

$X_L$is the amount of goods produced for local consumption in country L.
$X_E$is the amount of goods produced for export to country E.

Similarly, country E produces the good for both local consumption and export to country L. Therefore, the production function of a company in country E is,

$$Y = Y_L + Y_E \tag{2}$$

Where,

$Y_E$is the amount of goods produces for local consumption and Y_L represents the goods for export to country L.

We further assume that there are n firms in country L, and m companies in country E, therefore demand in country L, is D_L, which is equal to the combined production by its n firms for local consumption plus the combined export production from m companies from country E (equally for the demand in country E), so,

$$D_L = nX_L + \ mY_L \tag{3}$$

$$D_E = mY_E + nX_E \tag{4}$$

We also assume that both countries have the technology to regulate their pollution emissions. Let z_L be the share of pollution per unit produced by the homogeneous good in country L, and z_E the share and pollution per unit of output of the good for country E (it is clear that $z_L \geq 0$ and $z_E \geq 0$). We also assume that there is transboundary pollution between countries so that the emissions of the firms in each country are distributed proportionally between the emitting nation and the country with which the good is exchanged. This ratio depends on the amount of goods that are destined both for local consumption and the export market.[7] The same applies for the other nation involved in the reciprocal dumping.

Consequently, the total amount of pollutant emissions (z_L) in country L is given by the firms' production in country L –for local consumption– plus the quantity imported from country E, by multiplying each countries´ quotas, we get,

[7] *According to [25].*

$$Z_L = nX_L z_L + mY_L z_E \quad (5)$$

$$Z_E = mY_E z_E + nX_E z_L \quad (6)$$

If we consider the production marginal costs (s_L) of the good for country L, and country E, s_E, we assume there are differences in the structure costs between the two countries. Such costs are constant, and therefore equivalent to the average variable costs.[8]

The prices of the good in each of the countries are respectively p_L, and p_E, thus the benefits of the producer are given by,

$$\Pi_L = (p_L - s_L)X_L + (p_E - s_L)X_E \quad (7)$$

$$\Pi_E = (p_E - s_E)Y_E + (p_L - s_E)Y_L \quad (8)$$

That is, the marginal utility for the good $p_L - s_L$ regarding the production for local consumption of country L, plus the marginal utility of the homogeneous good, $p_E - s_E$ by the export production to country E.

Also, the price of the homogeneous good in country L is a function of the level of production of the good by domestic industries for local consumption, and the level of production of the imported good. Thus, for simplicity and without loss of generality we can consider the inverse function of demand as linear and expressed as,[9]

$$p_L = \alpha_L - \beta_L D_L \text{that is, } p_L = \alpha_L - \beta_L (nX_L + mY_L) \quad (9)$$

$$p_E = \alpha_E - \beta_E D_E \text{that is, } p_E = \alpha_E - \beta_E (nX_E + mY_E) \quad (10)$$

Let λ be the marginal cost of abating a unit of pollution (for simplicity we assume that it is the same in both countries); $\theta_L$and θ_E represent the amounts of pollution emitted before implementing environmental policy.[10] Thus, the cost per company of abatement is given by,

$$\upsilon_L = \lambda(\theta_L - z_L) \quad (11)$$

$$\upsilon_E = \lambda(\theta_E - z_E) \quad (12)$$

Hence the production unit cost for each company is,

$$s_L = c_L + \lambda(\theta_L - z_L) \quad (13)$$

$$s_E = c_E + \lambda(\theta_E - z_E) \quad (14)$$

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[8] *Implicitly, there is a number air good produced under perfect competition, and there is only one production in each country whose price is determined in a competitive market.*

[9]*Implicitly, we considered the utility function of both countries as $U_i = u(X_i, Y_i) + \mu_i$, where X and Y are the goods and μ_i is the expenditure on the numeraire good, i= L, E. Such approach avoids many theoretical difficulties, i.e. the effect of income.*

[10]*We also consider that θ_L, θ_E, z_L, z_E are above what the WHO considers an allowed maximum to be considered not harmful.*

Where c_L and c_E represent the technological cost component for each country.

Under these assumptions and considering that each firm establishes what amount of the good is consumed and how much is exported, and taking into account the assumptions of Cournot-Nash the first order maximization conditions are,

$$\frac{d\Pi_L}{dX_L} = 0 \quad \frac{d\Pi_L}{dX_E} = 0 \quad \frac{d\Pi_E}{dY_L} = 0 \quad \text{and} \quad \frac{d\Pi_E}{dY_E} = 0 \tag{15}$$

From where we obtain the solutions for variables $X_L,\ X_E, Y_{L,}Y_E$,

$$X_L = \frac{\left(\alpha_L - s_L + m(s_E - s_L)\right)}{\beta_L(m+n+1)} \tag{16}$$

$$X_E = \frac{\left(\alpha_E - s_L + m(s_E - s_L)\right)}{\beta_E(m+n+1)} \tag{17}$$

$$Y_L = \frac{(\ \alpha_L - s_E + n(s_L - s_E))}{\beta_L(m+n+1)} \tag{18}$$

$$Y_E = \frac{(\ \alpha_E - s_E + n(s_L - s_E))}{\beta_E(m+n+1)} \tag{19}$$

Therefore, the benefits for companies in countries L and E in their optimal point are given by,

$$\Pi_L^* = \ B_L X_L^2 + \beta_E X_E^2 \tag{20}$$

$$\Pi_E^* = \ B_E Y_E^2 + \beta_L Y_L^2 \tag{21}$$

Important to define parameter ϕ as the marginal cost to pollute which measures the damage caused for every unit of pollution produced.[11]

2.2 Comparative Statics

National welfare W_L for country L, is made up by consumers´ surplus C_{SL}in the country, producers´ surplus $n\Pi_L$, minus the total social cost per emitted pollutants ϕZ_L which gives us,

$$W_L = C_{SL} + n\Pi_L^* - \phi Z_L \tag{22}$$

$$W_E = C_{SE} + m\Pi_E^* - \phi Z_E \tag{23}$$

If we differentiate W_L and W_E from z_L and z_E we obtain,

$$\frac{dW_L}{dz_L} = \frac{d(C_{SL})}{dz_L} + \frac{d(n\Pi_L^*)}{dz_L} - \frac{d(\phi Z_L)}{dz_L} \tag{24}$$

$$\frac{dW_L}{dz_L} = \frac{\lambda n(nX_L + mY_L)}{m+n+1} + \frac{2\lambda n(m+1)(X_L + X_E)}{m+n+1} - \left(n\phi X_L + \frac{n\phi z_L \lambda(m+1)}{\beta_L(m+n+1)} - \frac{m\phi z_B n\lambda}{\beta_L(m+n+1)}\right) \tag{25}$$

[11] *Like [25] we assume that ϕ is constant, even though other authors like [26], consider that the marginal disutility is an increasing function that depends of the firms' production levels.*

$$\frac{dW_E}{dz_E} = \frac{C_{SE}}{dz_E} + \frac{m\Pi_E^*}{dz_E} - \frac{\theta Z_E}{dz_E} \tag{26}$$

$$\frac{dW_E}{dz_E} = \frac{m\lambda(nX_E+mY_E)}{m+n+1} + \frac{2\lambda m(n+1)(Y_L+Y_E)}{m+n+1} - \left(m\phi Y_E + \frac{m\phi z_E\lambda(n+1)}{\beta_E(m+n+1)} - \frac{n\phi z_L m\lambda}{\beta_E(m+n+1)}\right) \tag{27}$$

If we analyze the effects of the pollution quota taking into consideration the differentiated terms of the welfare function we obtain,

2.2.1 Consumer's surplus

$$dC_{SL=} \left(\frac{\lambda n(nX_L+mY_L)}{m+n+1}\right) dz_L \tag{28}$$

In this situation when the pollution quota increases then the production marginal costs and the total costs of the firms decrease, and as a result prices become attainable for consumers. Thus consumers' surplus rises.

2.2.2 Firm´s profit

$$dn\Pi_L^* = \left(\frac{2\lambda n(m+1)(X_L+X_E)}{m+n+1}\right) dz_L \tag{29}$$

When pollution quota increases, companies are benefited since they can reduce production costs, raise exports and overall competitiveness, and foster job creation. The result is an increase in producers´ surplus.

2.2.3 The social cost of polluting

$$d(\phi Z_L) = n\left(X_L + X_E + \frac{(m+1)(\beta_L+\beta_E)\lambda z_L}{\beta_L\beta_E(m+n+1)}\right) dz_L \tag{30}$$

Clearly by increasing the pollution quota its levels are added in the environment and thus the social cost and the cost of polluting also rise, that is $\frac{dZ_L}{dz_L} > 0$. Likewise a reduction inz_L decreases contaminants to the environment, which is positive result for a country.

Given the symmetry of the model the same reasoning is valid for z_E and the three components of the welfare function for the foreign country.

2.3 Optimal Pollution Quotas

We can calculate z_L^* and z_E^* by deriving

$$\frac{dW_L}{dz_L} = 0 \text{ and } \frac{dW_E}{dz_E} = 0 \tag{31}$$

By solving the simultaneous equations for z_L and z_E we obtain,

$$z_L^* = \frac{\lambda\big(2(n+1)(\beta_L(m+1)X+m\beta_E Y)+\beta_L(n+1)D_L+m\beta_E D_E\big)\big)-\phi(m+n+1)(\beta_L(n+1)X_L+m\beta_E Y_E)}{\phi\lambda(m+n+1)} \tag{32}$$

$$z_E^* = \frac{\lambda\big(2(m+1)(\beta_E(n+1)Y+n\beta_L X)+\beta_E(m+1)D_E+n\beta_L D_L\big)\big)-\phi(m+n+1)(\beta_E(m+1)Y_E+n\beta_L X_L)}{\phi\lambda(m+n+1)} \tag{33}$$

Since the parameters of the previous equations are by definition positive, z_L^*, is determined by the intensity of the parameters λ and ϕ which determine the positive or negative sign of the optimal quota that the government imposes on firms.

From the previous equations we can see two generic settings: when $\phi \gg \lambda$ and when $\lambda \gg \phi$which can be expressed through the following two propositions.

Proposition 1. For a non-cooperative equilibrium, the quota that maximizes welfare is:

$$\text{If } \boldsymbol{\phi} \gg \boldsymbol{\lambda} \text{ then } \boldsymbol{z_L^*} = \mathbf{0}$$

Therefore if the marginal cost to pollute is greater than the abatement costz_L^*would be negative and hence $z_L^* = 0$. This meaning that the marginal cost to pollute is higher and the government would prioritize the social cost of polluting over the other elements in the welfare function, such as firms´ profit (which increase the cost of production) and consumers' surplus (who have an impact due to the increase in the final price of goods).

Proposition 2. The maximum welfare quota in a non-cooperative equilibrium would be:

$$\text{If } \boldsymbol{\lambda} \gg \boldsymbol{\phi} \text{ then } \boldsymbol{z_L^*} > \mathbf{0}$$

In this case,λ increases singinficantly and thus the abatement cost is not inexpensive in economic terms and the government would allow a certain polluting quota for companies to be competitive and not have an additional marginal production cost. Also, consumers would not be affected since prices would not increase substantially. In this scenario, the government authorizes firms a certain amount of positive pollution $z_L^* > 0$ even if this implies a higher amount and therefore favors the firms and consumers benefits above the harmful effects on the environment.

If none of the previous conditions are met, then the magnitude of the optimal quota will depend on the value of the other parameters to calculate z_A^* and its interrelations. Still the sign and intensity of z_A^* is ambiguous and is contingent on multiple factors.

3. THE MODEL FOR A POLLUTION TAX

3.1 Specification

The model is basically similar to the previous so X, Y, n, m, D_L, D_E, p_L, p_E, ϕ, λ and θ are defined in the same way.

We assume firms in both countries have the same technology to abate pollution. Therefore z is the amount of unit of pollution produced by the homogenous good in countries $L$and E. Accordingly,the total amount of released pollution Z_L for country L is given by the production for local consumption by the country's firms plus the imported production from country E multiplied by their quotas, therefore,

$$Z_L = nX_Lz + mY_Lz \tag{34}$$

Similarly, the total amount of released pollutants Z_E for country E is given by,

$$Z_E = mY_E z + nX_E z \tag{35}$$

If t_L and t_E are the taxes for each unit of released pollution for both countries L and E then the cost for a firm regarding the emission of pollutants is,

$$v_L = \lambda(\theta - z) + t_L z \tag{36}$$

$$v_E = \lambda(\theta - z) + t_E z \tag{37}$$

And the cost of pollution emission for a firm is expressed by

$$V_L = \lambda(\theta - z) + t_E z \tag{38}$$

$$V_E = \lambda(\theta - z) + t_L z \tag{39}$$

If we consider the costs c_L and c_E as the components of the marginal cost determined by technology and the market of the good for both countries, we assume there are differences in their cost structures and they are constant and therefore equivalent to the average variable costs. In this way the unitary production cost for company X_L and Y_E is,

$$s_L = c_L + \lambda(\theta - z) + t_L z \tag{40}$$

$$s_E = c_E + \lambda(\theta - z) + t_E z \tag{41}$$

And the unit production cost for each firm is,

$$S_L = c_L + \lambda(\theta - z) + t_E z \tag{42}$$

$$S_E = c_E + \lambda(\theta - z) + t_L z \tag{43}$$

Under these circumstances z is the amount of emissions per unit of product that firms establish unilaterally, since decreasing the amount of emitted pollutants can mean considerable savings regarding their pollution taxes.

Therefore, when the abatement cost is higher than the pollution tax, firms do not profit if they reduce their emissions, so they would rather keep paying the corresponding tax (the amount they keep polluting per product unit is θ). If on the contrary they decided not to pollute, and pay the cost of abatement and not the tax, it can be expressed by,

$$z = \begin{cases} 0 & \text{if } t_L, t_E \geq \lambda \\ \theta & \text{if } t_L, t_E < \lambda \end{cases} \tag{44}$$

And therefore,

$$s_L = \begin{cases} c_L + \lambda\theta & \text{if } t_L \geq \lambda \\ c_L + t_L\theta & \text{if } t_L < \lambda \end{cases} \tag{45}$$

$$s_E = \begin{cases} c_E + \lambda\theta & \text{if } t_E \geq \lambda \\ c_E + t_E\theta & \text{if } t_E < \lambda \end{cases} \tag{46}$$

$$S_L = \begin{cases} c_L + \lambda\theta & \text{if } t_E \geq \lambda \\ c_L + t_E\theta & \text{if } t_E < \lambda \end{cases} \tag{47}$$

$$S_E = \begin{cases} c_E + \lambda\theta & \text{if } t_L \geq \lambda \\ c_E + t_L\theta & \text{if } t_L < \lambda \end{cases} \tag{48}$$

$$Z_L = \begin{cases} 0 & \text{if } t_L, t_E \geq \lambda \\ nX_L\theta + mY_L\theta & \text{if } t_L, t_E < \lambda \end{cases} \tag{49}$$

$$Z_E = \begin{cases} 0 & \text{if } t_L, t_E \geq \lambda \\ mY_E\theta + nX_E\theta & \text{if } t_L, t_E < \lambda \end{cases} \tag{50}$$

Calculating the optimum tax is pointless when $t_L \geq \lambda$ and $t_E \geq \lambda$, in this case the amount of pollution is zero, regardless of the tax amount. But when $t_L < \lambda$ and $t_E < \lambda$ firms prefer to pay the tax and there is no pollution emission reduction. In this case W does depend of t.

The price for the good for each country is$p_L$andp_E, therefore producers benefits are given by,

$$\Pi_L = (p_L - s_L)X_L + (p_E - S_L)X_E \tag{51}$$

$$\Pi_E = (p_E - s_E)Y_E + (p_L - S_E)Y_L \tag{52}$$

That is,

$$\Pi_L = (p_L - c_L - t_L\theta)X_L + (p_E - c_L - t_E\theta)X_E \tag{53}$$

$$\Pi_E = (p_E - c_E - t_E\theta)Y_E + (p_L - c_E - t_L\theta)Y_L \tag{54}$$

Furthermore the price of the homogenous good for country L is a function of the level of production of the good by local industries for local consumption, and the level of production of the imported good. For simplicity we can consider the demand inverse function as linear,

$$p_L = \alpha_L - \beta_L D_L \tag{55}$$

$$p_L = \alpha_L - \beta_L(nX_L + mY_L) \tag{56}$$

$$p_E = \alpha_E - \beta_E D_E \tag{57}$$

$$p_E = \alpha_E - \beta_E(nX_E + mY_E) \tag{58}$$

Therefore the national welfare W_L, for country L is given by the consumer´s surplus C_{SL}, plus the producer´s surplus $n\Pi_L$, plus the pollution tax collected $t_L Z_L$, minus the total social cost for emission of pollutants ϕZ_L, hence,

$$W_L = C_{SL} + n\Pi_L + t_L Z_L - \phi Z_L \tag{59}$$

Equally, the welfare for country E is expressed by,

$$W_E = C_{SE} + m\Pi_E + t_E Z_E - \phi Z_E \tag{60}$$

Under these assumptions and considering that each firm establishes what amount of the good is consumed in the country and what is exported. Using the Cournot-Nash assumptions the first order maximization conditions are,

$$\frac{d\Pi_L}{dX_L} = 0 \quad \frac{d\Pi_E}{dY_L} = 0 \tag{61}$$

$$\frac{d\Pi_L}{dX_E} = 0 \quad \frac{d\Pi_E}{dY_E} = 0 \tag{62}$$

From which we obtain the solutions for the variables X_L,X_E,Y_L,Y_E

$$X_L = \frac{mS_E - s_L + \alpha_L - ms_L}{\beta_L(m+n+1)} \tag{63}$$

$$X_E = \frac{\alpha_E - mS_L - S_L + ms_E}{\beta_E(m+n+1)} \tag{64}$$

$$Y_L = \frac{\alpha_L - nS_E - S_E + ns_L}{\beta_L(m+n+1)} \tag{65}$$

$$Y_E = \frac{nS_L - s_E + \alpha_E - ns_E}{\beta_E(m+n+1)} \tag{66}$$

The benefits for companies in countries L and E in their optimum point are given by,

$$\Pi_L = \beta_L X_L^2 + \beta_E X_E^2 \tag{67}$$

$$\Pi_E = \beta_E Y_E^2 + \beta_L Y_L^2 \tag{68}$$

3.2 Comparative statics

Important to remember that national welfare W_L and W_E for countries L and E is defined by,

$$W_L = CS_L + n\Pi_L + t_L Z_L - \phi Z_L \tag{69}$$

$$W_E = CS_E + m\Pi_E + t_E Z_E - \phi Z_E \tag{70}$$

If we differentiate W_L and W_E from t_L and t_E, we get,

$$\frac{dW_L}{dt_L} = \frac{d(CS_L)}{dt_L} + \frac{d(n\Pi_L)}{dt_L} + \frac{d(t_L Z_L)}{dt_L} - \frac{d(\phi Z_L)}{dt_L} \tag{71}$$

$$\frac{dW_L}{dt_L} = -\frac{\theta(nX_L + mY_L)(m+n)}{m+n+1} - \frac{2\theta n\beta_L X_L}{m+n+1} + \theta(nX_L + mY_L) - \frac{t_L\theta^2(m+n)}{\beta_L(m+n+1)} + \frac{\phi\theta^2(m+n)}{\beta_L(m+n+1)} \tag{72}$$

$$\frac{dW_E}{dt_E} = \frac{d(CS_E)}{dt_E} + \frac{d(n\Pi_E)}{dt_E} + \frac{d(t_E Z_E)}{dt_E} - \frac{d(\phi Z_E)}{dt_E} \tag{73}$$

$$\frac{dW_E}{dt_E} = -\frac{\theta(nX_E + mY_E)(m+n)}{m+n+1} - \frac{2\theta m\beta_E Y_E}{m+n+1} + \theta(nX_E + mY_E) - \frac{t_E\theta^2(m+n)}{\beta_E(m+n+1)} + \frac{\phi\theta^2(m+n)}{\beta_E(m+n+1)} \tag{74}$$

The pollution tax has the following effects in terms of W,

3.2.1 Consumers´ surplus

$$d(CS_L) = \left(-\frac{\theta(nX_L+mY_L)(m+n)}{m+n+1}\right)dt_L \tag{75}$$

In this case, when pollution taxes decrease then production marginal cost and total cost for the firms fall and consumers benefit of lower prices and thus consumers' surplus increases.

3.2.2 Companies´ profit

$$d(n\Pi_L^*) = \left(-\frac{2\theta n\beta_L X_L}{m+n+1}\right)dt_L \tag{76}$$

When the pollution tax decreases, which companies favored since they can reduce their production costs, exports are promoted, competitiveness is increased and job creation is stimulated. That is producer´s surplus grows.

3.2.3 Tax revenue

$$d(t_L Z_L) = \left(\theta D_L - \frac{t_L\theta^2(m+n)}{\beta_L(m+n+1)}\right)dt_L \tag{77}$$

The effect of the pollution tax regarding tax revenue is ambiguous, since increasing production translates into higher tax income due to the amount of emitted pollution, however, the pollution tax increase translates into a production cost rise and therefore the combined effect is uncertain.

3.2.4 The social cost for polluting

$$d(\phi Z_L) = \left(-\frac{\phi\theta^2(m+n)}{\beta_L(m+n+1)}\right)dt_L \tag{78}$$

Evidently decreasing the tax increases the level of pollution so the social cost also increases. The same way an increase in$t_L$reduces pollution.

The analysis for t_E is similar to the above, if we consider the foreign country in terms of W_E due to the symmetrical character of the model.

3.3 Optimal Tax.

To calculate t_L^* and t_E^*, we consider,

$$\frac{dW_L}{dt_L} = 0 \text{ and } \frac{dW_E}{dt_E} \tag{79}$$

The derivatives were calculated by solving t_L and t_E we get,

$$t_L = \phi + \frac{\beta_L(D_L - 2nX_L\beta_L)}{\theta(m+n)} \tag{80}$$

$$t_E = \phi + \frac{\beta_E(D_E - 2mY_E\beta_E)}{\theta(m+n)} \tag{81}$$

Since all the involved parameters in the previous equation are by definition positive, we can conclude−regarding the tax− that if the marginal cost to pollute is too high then the optimum value for t_L^* as well as $t_E^*$are positive. If we consider that the social marginal cost to pollute is high then the government will value more the harmful effects than the other welfare components in the function that involve consumers, producers and the government through tax collection. Which can be expressed in the following proposition.

Proposition 3. In a non-cooperative equilibrium, the pollution tax that maximizes welfare is,

If $\phi \gg 0$, then $t_L^* > 0$, $t_E^* > 0$

Considering that the function of W is not necessarily continuous with respect to t, and how we define s_L,s_E,S_L and S_E the only possible discontinuous point is $t = \lambda$.

We focus our analysis in the possible discontinuation of W in $t = \lambda$ and using lateral limits (44), (45), (46), (47), (48), (49) and (50) we get,

$$lim_{t\to\lambda^+} W_L = CS_L + n\Pi_L^* + t_L Z_L - \phi Z_L \quad (82)$$

$$lim_{t\to\lambda^+} W_L = CS_L + n\Pi_L^* \quad (83)$$

$$lim_{t\to\lambda^-} W_L = CS_L + n\Pi_L^* + t_L Z_L - \phi Z_L \quad (84)$$

$$lim_{t\to\lambda^-} W_L = CS_L + n\Pi_L^* + \lambda(nX_L\theta + mY_L\theta) - \phi(nX_L\theta + mY_L\theta) \quad (85)$$

$$lim_{t\to\lambda^-} W_L = CS_L + n\Pi_L^* + (\lambda - \phi)(nX_L\theta + mY_L\theta) \quad (86)$$

From (83) and (86) we get,

$$lim_{t\to\lambda^+} W_L - lim_{t\to\lambda^-} W_L = (\phi - \lambda)(nX_L\theta + mY_L\theta) \quad (87)$$

From where we can conclude,

$$lim_{t\to\lambda^+} W_L - lim_{t\to\lambda^-} W_L > 0 \quad if\ \phi > \lambda \quad (88)$$

$$lim_{t\to\lambda^+} W_L - lim_{t\to\lambda^-} W_L = 0 \quad \text{if} \quad \phi = \lambda \quad (89)$$

$$lim_{t\to\lambda^+} W_L - lim_{t\to\lambda^-} W_L < 0 \quad if\ \phi < \lambda \quad (90)$$

With a similar reasoning we get,

$$lim_{t\to\lambda^+} W_E - lim_{t\to\lambda^-} W_E = (\phi - \lambda)(mY_E\theta + nX_E\theta) \quad (91)$$

From where we conclude that,

$$lim_{t\to\lambda^+} W_E - lim_{t\to\lambda^-} W_E > 0 \quad if\ \phi > \lambda \quad (92)$$

$$lim_{t\to\lambda^+} W_E - lim_{t\to\lambda^-} W_E = 0 \quad \text{if} \quad \phi = \lambda \quad (93)$$

$$lim_{t\to\lambda^+} W_E - lim_{t\to\lambda^-} W_E < 0 \quad if\ \phi < \lambda \quad (94)$$

Which we can express with the following proposition,

Proposition 4. If $\boldsymbol{\phi} \geq \boldsymbol{\lambda}$ then the tax is $\boldsymbol{t}_L^*, \boldsymbol{t}_E^* \geq \boldsymbol{\lambda}$ and therefore there are no emissions of pollutants. If $\boldsymbol{\phi} \geq \boldsymbol{\lambda}$ then the tax is $\boldsymbol{t}_L^*, \boldsymbol{t}_E^* < \boldsymbol{\lambda}$ and there is no reduction in the emission of pollutants.

Intuitively if the marginal cost to pollute is high, then the social cost to pollute is a priority over the other terms of W, which causes the pollution tax to be higher than the abatement cost, and naturally companies decide not to contaminate. On the contrary, if the marginal cost to pollute is not excessive with regards the pollution abatement cost then t is smaller than the abatement cost, and thus firms decide not to reduce emissions.

We must remember the fact that for quotas, firms cannot decide how much to contaminate, but it is the government who establishes the pollution limit. However with taxes, companies can choose two possible options: not to emit pollution or reduce to a minimum the amount they emit; in such a way that if $\phi \gg \lambda$, firmswill decide reducing to a maximum their pollution emissions exactly as expressed in proposition 1. This observation is resumed in one last proposition.

Proposition 5. Establishing quotas and taxes on companies as an environmental policy has the same results in $\boldsymbol{W}$ when marginally the cost to pollute is higher than the cost of abatement.

4. CONCLUSION

Governments must promote economic development and at the same time assure a sustainable development of their resources. Therefore they must implement a number of environmental policy measures on firms without affecting productivity and controlling pollution to acceptable levels. So governments cannot impose strict policy instruments, since this would translate into higher production costs in detriment of their productivity and foreign direct investment.

Our work develops a Cournot oligopoly model under reciprocal dumping conditions for two small countries. The firms involved in this type of international commerce share part of their production for local consumption and the rest they export. Companies in both countries through their production processes pollute, however they have the technology to decrease emissions. The model uses two kinds of control as environmental policy instruments: environmental quotas and pollution taxes.

Lastly, we assume transboundary pollution between both countries, this means that part of the emissions affect the local country and another part impact the foreign one with which commerce is carried out (emissions are evenly distributed regarding the amounts of the produced good, for local and foreign consumption). With these assumptions we present our conclusions.

Regarding pollution quotas, if the cost of abatement is high in comparison to the social cost to pollute, the government will allow firms certain amount of emissions. Companies favor this, since they can reduce their production costs with a positive impact on competiveness and benefit consumers and producers. However if the social cost to pollute were high in comparison to the abatement cost, then the best policy would be to impose firms a zero pollution quota. This means the government will prioritize the potential harm to the environment, even if production costs have to rise and thus consumers final price. For the second scenario, if the abatement cost were too high in comparison to the marginal pollution cost, then the government would allow a certain amount of pollution, accordingly production cost decrease, which firms favor, ´profit and consumers´ price. Nonetheless emissions increase significantly and so does the social cost for pollution.

Regarding pollution taxes, if the marginal cost to pollute were high, then the government will impose a tax to emissions, so it would care more for the possible negative impacts of pollution above the marginal production costs. This would affect consumers' prices of the goods. Equally, if the marginal cost for polluting is higher then the abatement cost, then the optimal tax has to be higher than the cost of abatement, thus firms decide not to pollute. Since it would be more costly to pay the tax than to reduce emissions. In the opposite scenario that the marginal cost to pollute were less than the abatement cost, then the optimal tax would have to be less than the cost, and firms would not reduce their emissions, since they would not have the economic incentive to do so, and it would be less expensive to pay for their emissions.

Therefore, this work highlights the importance of regulating as much as possible the pollution emissions of firms, in a way that will favor their competitiveness and also consumers benefit from it.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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