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Documento de Trabajo 2011-02

SERIE: Economía del Cambio Climático

CÁTEDRA Fedea-Iberdrola

January 2011

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ISSN:1696-750X

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STRATEGIC BEHAVIOUR OF EXPORTING AND IMPORTING COUNTRIES OF A NON-RENEWABLE NATURAL RESOURCE: TAXATION AND CAPTURING RENTS[1]

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Abstract

Taking into account the great importance which the non-renewable energy resources have nowadays, and particularly the effects of their consumption on the environment and the problems associated with capturing rents, this paper analyses, through a two-period model, the interaction between producers and importers of a non-renewable energy resource, trying to determine the possible strategic behaviour of both agents, and analyzing the influence on the balance between agents considering or not considering the environmental effects induced by the consumption of such a resource, as well as the simultaneity or not of the decisions of the participants.

JEL Numbers: Q53, Q31, C72, H23.

Keywords: Environmentla taxation, Dynamic games, Non-renewable resources.

Resumen

Teniendo en cuenta la gran importancia que tienen en la actualidad los recursos energéticos no renovables, y en particular los efectos de su consumo sobre el medio ambiente y los problemas asociados a la captación de la renta del recurso, este artículo analiza, mediante un modelo de dos períodos, la interacción entre los productores y los importadores de un recurso energético no renovable, tratando de determinar los posibles comportamientos estrátegicos de ambos agentes, y analizando la influencia sobre el equilibrio de la consideración o no por parte de los agentes de los efectos ambientales provocados por el consumo de dicho recurso, así como de la simultaneidad o no de las decisiones de los participantes.

JEL : Q53, Q31, C72, H23.

Palabras Clave: Impuestos ambientales, Juegos dinámicos, Recursos naturales no renovables.

[1] We acknowledge the financial support of the Spanish Ministry of Science and Innovation (research project ECO2009-14586-C02-01). We also thank J. B. Readman for his linguistic revision of the text.

1. Introduction

Energy, key element in the economic and social development, nowadays faces multiple challenges, among which we can highlight all the problems related to climate change, which are caused in large measure by the production and consumption of energy (see Stern, 2006). This has given way to the development of different taxes which try to mitigate the disruptive effects of energy on the environment.

When the sources of energy come from scarce resources, frequently they are concentrated in certain countries, which makes the international market for these products non-competitive. In this context, if the country which extracts the resource is different from the country where the resource is consumed (as happens very often), problems related to the sharing of the rent of the resource between producers and consumers appear. So, the introduction of environmental taxes by importing countries can lead them to appropriate part of the returns of the exporters, and then a reaction by the latter can be expected, as they try to divert part of the takings through them through an increase in their price, resulting in a strategic interaction.

In this context, we try to analyse, from a theoretical point of view, the existing relationship between a producer cartel and an importing country (or coalition of countries) of a non-renewable natural energy resource the consumption of which provokes environmental damage, studying all possible strategic behaviours which can derive from this relationship. We will study the case in which only the importing country is concerned by the environmental deterioration caused by the consumption of the resource and also the case in which both importer and exporter are concerned. On the other hand, we will study the case in which the actions of the agents are simultaneous and also the cases in which they are sequential. In this way, a fundamental question in this line of research will be if the taxes which are introduced by the importers affect the prices fixed by the exporters.

There is an extensive literature related to the interaction between producers and importers of a scarce resource. So, Karp and Newbery (1991) analyse the performance of the world oil market through a model in which the supply side is composed of OPEC (symmetrical duopoly with zero extracting costs) and the rest of the world (competitive with constant and uniform extracting costs). Producers decide the extraction rate of the resource, whereas the consumers fix a tax on the oil. They study the path of evolution of the variables, arriving to the conclusion that the price will increase over time, whereas the tax will be high at the beginning and will fall gradually as the world demand becomes more elastic.

Moreover, they compare the equilibrium of the world market with the competitive equilibrium without taxes, and finding that the extraction ratio is smaller than in the competitive equilibrium and that the market power of the buyers is greater than that of the OPEC. In a subsequent paper, Karp and Newbery (1992) study the case in which the suppliers are competitive but the importers have market power and establish a tax on the oil, analysing and comparing the evolution path of the variables both in the open loop and Markovian Nash equilibrium.

On the other hand, Wirl (1994, 1995), Wirl and Dockner (1995), Tahvonen (1996), Rubio and Escriche (2001), Liski and Tahvonen (2004), Rubio (2007) or Strand (2008) study the relationship between a cartel of producers of a generic non-renewable resource which wants to maximize profits, and a government, which is an importer of the resource, which uses a tax on the resource in order to maximize the welfare of his consumers, although the papers present differences when the models are introduced. Thereby, Wirl (1994) considers that the consumption of energy provokes two types of environmental damages: flow (emission by polluters) and stock (acumulation of polluters in the atmosphere). In this context he analyses both the cooperative equilibrium and the Nash equilibrium in Markov strategies. One of the main conclusions he obtains is that the producers have capacity to co-opt part of the tax, although this capacity declines as the stock of the externality increases. Moreover, the non-cooperation is beneficial for the environment, because it delays the effect of the stock externalities.

In Wirl (1995), the model is similar to the previous one, but it leaves the flow externality out of the picture and it incorporates extraction costs of the resource and the depreciation with the passing of time of the stock of accumulated polution. The existence of two state variables prevents him from obtaining an analytical solution of the problem, but he obtains the stationary solution though economic argumentation, arriving to the conclusion that the stationary state of the model is independent of the structure of the market and the type of strategies.

In the case of Wirl and Dockner (1995), the authors assume that the government values the incomes from taxes by themselves, and consider for the supply two scenarios: perfect competition and cartel. The main result they obtain is that if the government also uses the tax with the objective of increasing its incomes, then it can improve the welfare of the consumers with respect to a benevolent government, because it weakens the reaction of the producers to the impact of the environmental taxes. In any case, the long run environmental damage will increase, because the government will be less ready to sacrifice the incomes associated with the tax.

Tahvonen (1996) studies the case in which the producers are Stackelberg leaders and compares it with the Pareto optimum, reaching the conclusion that the power of monopoly consists only of delaying the extraction. In this context, a model is also considered in which pollution is reversible and the stock of the resource affects the extraction, obtaining as a result that the buyers will have monopsony power, reducing the capacity of the producers for co-opting part of the incomes from the tax.

Rubio and Escriche (2001) compare the simultanueous equilibrium with the Stackelberg equilibrium of the game, obtaining that, in the case in which the cartel of exporters act as leader, the equilibrium will be identical to the simultaneous equilibrium, whilst if the Stackelberg leader is the importing coalition, it will have strategic advantage, allowing that coalition to increase the welfare of the consumers and reduce the profits of the cartel.

Liski and Tahvonen (2004) use the model to determine if the establishment of a carbon tax applied on the fuels can make it possible for the importing countries to co-opt part of the rents of the OPEC, arriving the conclusion that if there is no environmental damage and the price of the producer is increasing, the tax will be a pure importation tariff, whilst if environmental damage exists and the price of the producer is decreasing, the tax will include a subvention to the importation. Only when the price of the producer is flat will we have a pure pigouvian tax equal to the present value of the marginal damage.

In the case of Rubio (2007), this interaction between producers and importers is studied but assuming that there exist *n* importing countries who act in a non-cooperative way. He proves that it is not necessary for the importers to have strategic advantage in order to have the possibility of using the tariff strategically to capture part of the rents of the monopolist. Moreover, in order to carry this out it is not necessary that the importer countries act in a cooperative way, although the parto f the rent that can be captured decreases substantially with the number of impoting countries.

Finally, Strand (2008) puts forward a static model (in a different way of the previous works) and obtains the non-cooperative equilibrium between exporters and importers, comparing it with a series of alternative situations in order to analyse the effects on the welfare in the different cases.

However, all this literature tries mainly to study the path of evolution of the variables of the model, rather than analysing the relationship among the variables in the different cases. For that reason, in this paper we are going to use a model which permits us, in an analytical way, to obtain and compare the optimal solutions in the different cases which can appear in order to see which situations are more beneficial for each party and for the environment. For that, in a different way to the majority of the papers previously cited, we are going to use a model in discrete time, because it will permit us a clearer formulation and for the questions we want to answer a more complicated model is not necessary.

In this way, the paper is divided into five sections, including this introduction. In the second section we will present the basic model we are going to use, whilst in the third and the fourth we will analyse the different cases and the relations among them. The paper will finish with a section with the resumé and conclusions.

2. The model

There exists a cartel producer of a non-renewable natural resource (for example oil) and a country (or a coalition of countries) which imports such a resource from the cartel[2]. The model considers two periods, therefore we have a dynamic problem. In each period the cartel decides the price of the resource, whilst the importer country establishes a tax on the resource.

The consumption of the resource generates a pollution which accumulates in the atmosphere, in such a way that in each period *t* the stock of pollution (S_t) will be given by

$$S_t = S_{t-1} + q_t \qquad (1)$$

q_t being the consumption of the resource in the importing country in period *t*. We assume that the stock of pollution does not decline, because the decline is very slow (about 200 years) and is non-linear. Moreover, this assumption is not crucial because a unit of measure of the energy which gives rise to the emission of a unit of pollutant to the atmosphere can be used (see Wirl and Dockner, 1995).

[2] It is assumed that the resource is not consumed in the producer country, whilst the importing country does not produce that resource.

That stock of pollution generates a negative externality in each period we model, following the literature (see Wirl, 1995 or Liski and Tahvonen, 2004), through a quadratic damage function of the form $\frac{1}{2}cS_t^2$, with $c > 0$.

The cartel will try to maximize its profits, which will be given by the diffrence between its incomes and its costs of extraction of the resource, whilst the importer country will try to maximize the welfare of its citizens which will be given by the sum of the consumers´ surplus and the takings from taxes[3], minus the environmental damage provoked by the consumption of the resource. We assume that the demand function of the resource in each period in the importing country is linear[4] of the form

$$q_t = a - b(p_t + \tau_t) \tag{2}$$

p_t and τ_t being, respectively, the price of the resource, fixed by the cartel, and the tax established by the government of the importing country in period t, $a > 0, b > 0, a > c$. Although the resource is non-renewable, we assume that no scarcity problems exist, so the extraction costs will be constant. We will assume zero costs because that does not affect the essence of the results.

In the following two sections we are going to present the different cases analysed using this model, first when only the government of the importing country is worried about the environmental damage provoked by the consumption of the resource (section 3), and, then, when also the producers are worried about the environmental damage (section 4).

3. Environmental concern of the importer

3.1 Absence of taxes (SI)

In the first place, we are going to consider the case in which the government of the importing country does not establish any tax on the consumption of the resource. In this case, we have a static

[3] It is assumed that the takings obtained in the importing country from the tax are given back to the citizens through lump-sum transfers.
[4] We use a linear demand function because it eases the attainment of the analytical solutions of the problem, but we could use other different functional forms.

optimization problem in which the producer will set the price which maximizes its profits, and the importing country will have no capacity to influence that price. So, the problem of the cartel will be

$$\underset{p_1, p_2}{Max}\,\Pi = p_1 q_1 + p_2 q_2 = p_1(a - bp_1) + p_2(a - bp_2) \tag{3}$$

From the necessary and sufficient conditions of optimality we obtain that, in absence of taxes

$$\begin{array}{lll} p_1^{SI} = \dfrac{a}{2b} & q_1^{SI} = \dfrac{a}{2} & S_1^{SI} = S_0 + \dfrac{a}{2} \\ p_2^{SI} = \dfrac{a}{2b} & q_2^{SI} = \dfrac{a}{2} & S_2^{SI} = S_0 + a \end{array} \tag{4}$$

Then, the welfare of the consumers in the importing country will be given by

$$\begin{aligned} W^{SI} &= u_1 + u_2 - \frac{1}{2}cS_1^2 - \frac{1}{2}cS_2^2 = \frac{\left(\frac{a}{b} - p_1\right)q_1}{2} + \frac{\left(\frac{a}{b} - p_2\right)q_2}{2} - \frac{1}{2}cS_1^2 - \frac{1}{2}cS_2^2 \\ W^{SI} &= \frac{a^2}{4b} - c\left(S_0^2 + \frac{5}{8}a^2 + \frac{3}{2}S_0 a\right) \end{aligned} \tag{5}$$

u_t being the consumer´s surplus in the importing country in period t deriving from the consumption of the resource.

On the other hand, the profits of the cartel will be

$$\Pi^{SI} = p_1 q_1 + p_2 q_2 = \frac{a^2}{2b} \tag{6}$$

3.2 Taxes (I)

Let us assume that the government of the importing country decides to introduce a tax τ_t in each period on the consumption of the resource. In this way, the problem of the cartel producer will now be the following

$$\underset{p_1,p_2}{Max}\,\Pi = p_1q_1 + p_2q_2 = p_1(a - bp_1 - b\tau_1) + p_2(a - bp_2 - b\tau_2)$$

$$CPO \tag{7}$$

$$\frac{\partial\Pi}{\partial p_1} = a - 2bp_1 - b\tau_1 = 0 \quad \Rightarrow \quad p_1 = \frac{a - b\tau_1}{2b}$$

$$\frac{\partial\Pi}{\partial p_2} = a - 2bp_2 - b\tau_2 = 0 \quad \Rightarrow \quad p_2 = \frac{a - b\tau_2}{2b}$$

On the other hand, the government of the importing country will set the taxes in such a way that the welfare of its citizens will be maximized, that is

$$\begin{aligned}\underset{\tau_1,\tau_2}{Max}\,W &= u_1 + \tau_1q_1 - \frac{1}{2}cS_1^2 + u_2 + \tau_2q_2 - \frac{1}{2}cS_2^2 = \frac{\left(\frac{a}{b} - p_1 - \tau_1\right)(a - bp_1 - b\tau_1)}{2} + \\ &+ \tau_1(a - bp_1 - b\tau_1) - \frac{1}{2}c(S_0 + a - bp_1 - b\tau_1)^2 + \frac{\left(\frac{a}{b} - p_2 - \tau_2\right)(a - bp_2 - b\tau_2)}{2} + \\ &+ \tau_2(a - bp_2 - b\tau_2) - \frac{1}{2}c(S_0 + a - bp_1 - b\tau_1 + a - bp_2 - b\tau_2)^2\end{aligned} \tag{8}$$

Solving this maximization, we obtain the best-response functions of the importer

$$\begin{aligned}\tau_1 &= \frac{3ac + abc^2 + 2cS_0 + bc^2S_0 - 2bcp_1 - b^2c^2p_1 - bcp_2}{1 + 3bc + b^2c^2} \\ \tau_2 &= \frac{2ac + abc^2 + cS_0 - bcp_1 - bcp_2 - b^2c^2p_2}{1 + 3bc + b^2c^2}\end{aligned} \tag{9}$$

With the best-response functions of both, we calculate the Nash equilibrium, which we present below

$$\begin{aligned}
&p_1^I = \frac{2a - 4bcS_0 - b^2c^2S_0}{4b + 6b^2c + b^3c^2} \qquad \tau_1^I = \frac{6ac + abc^2 + 8cS_0 + 2bc^2S_0}{4 + 6bc + b^2c^2} \qquad q_1^I = \frac{2a - 4bcS_0 - b^2c^2S_0}{4 + 6bc + b^2c^2} \\
&p_2^I = \frac{2a + abc - 2bcS_0}{4b + 6b^2c + b^3c^2} \qquad \tau_2^I = \frac{4ac + abc^2 + 4cS_0}{4 + 6bc + b^2c^2} \qquad q_2^I = \frac{2a + abc - 2bcS_0}{4 + 6bc + b^2c^2} \\
&S_1^I = \frac{2a + 4S_0 + 2bcS_0}{4 + 6bc + b^2c^2} \qquad S_2^I = \frac{4a + abc + 4S_0}{4 + 6bc + b^2c^2} \\
&W^I = \frac{8a^2 + 24a^2bc + 9a^2b^2c^2 + a^2b^3c^3 - 24abcS_0 - 72ab^2c^2S_0 - 24ab^3c^3S_0 - 2ab^4c^4S_0}{2b(4 + 6bc + b^2c^2)^2} + \\
&+ \frac{-32bcS_0^2 - 76b^2c^2S_0^2 - 28b^3c^3S_0^2 - 3b^4c^4S_0^2}{2b(4 + 6bc + b^2c^2)^2} \\
&\Pi^I = \frac{8a^2 + 4a^2bc + a^2b^2c^2 - 24abcS_0 - 8ab^2c^2S_0 + 20b^2c^2S_0^2 + 8b^3c^3S_0^2 + b^4c^4S_0^2}{b(4 + 6bc + b^2c^2)^2}
\end{aligned} \tag{10}$$

Therefore, as the assumption about the scarcity of the resource has not been introduced, the taxes fixed by the government of the importing country will be purely environmental. Thus, if the importing country had not taken into account the environmental damage that the consumption of the resource provokes, the taxes would be zero, and the government could not use them to influence the price set by the producers.

Proposition 1

The introduction of taxes on the comsumption of the resource by the importing country reduces the prices of the producer, the quantities and the stock of the pollution in both periods, altough the final price paid by the consumers is higher. Moreover, the welfare in the importing country is higher and the profits of the cartel are lower. .

Proof: See the Appendix.

3.3 Stackelberg. Leader: exporter (SX)

Until now we have considered the case in which the agents take their decisions simultaneously , but this may not be so. On this basis, in this section we assume that the exporting country is the first in deciding its prices, and that the importing country makes its decisions about the taxes knowing the price set by the producer. In the next section we will consider the opposite case.

Therefore, the problem of the importing country will remain the same as in the previous case, but not the problem of the producer, who will have to anticipate the reaction of the importer to the price which he fixes, incorporating this constraint at the time of maximizing its profits. That is, now the problem of the producer will be subject to the functions of best-response of the importer, obtained in the previous heading

$$\underset{p_1,p_2}{Max}\,\Pi = p_1q_1 + p_2q_2 = p_1(a - bp_1 - b\tau_1) + p_2(a - bp_2 - b\tau_2)$$
$$s.t$$
$$\tau_1 = \frac{3ac + abc^2 + 2cS_0 + bc^2S_0 - 2bcp_1 - b^2c^2p_1 - bcp_2}{1 + 3bc + b^2c^2} \qquad (11)$$
$$\tau_2 = \frac{2ac + abc^2 + cS_0 - bcp_1 - bcp_2 - b^2c^2p_2}{1 + 3bc + b^2c^2}$$

In this way, we will have that, in equilibrium

$$
\begin{aligned}
&p_1^{SX} = \frac{a-2bcS_0}{2b} \qquad \tau_1^{SX} = \frac{3ac+abc^2+4cS_0+7bc^2S_0+2b^2c^3S_0}{2+6bc+2b^2c^2} \qquad q_1^{SX} = \frac{a-2bcS_0-b^2c^2S_0}{2+6bc+2b^2c^2} \\
&p_2^{SX} = \frac{a-bcS_0}{2b} \qquad \tau_2^{SX} = \frac{2ac+abc^2+2cS_0+3bc^2S_0+b^2c^3S_0}{2+6bc+2b^2c^2} \qquad q_2^{SX} = \frac{a+abc-bcS_0}{2+6bc+2b^2c^2} \\
&S_1^{SX} = \frac{a+2S_0+4bcS_0+b^2c^2S_0}{2+6bc+2b^2c^2} \qquad S_2^{SX} = \frac{2a+abc+2S_0+3bcS_0+b^2c^2S_0}{2+6bc+2b^2c^2} \\
&W^{SX} = \frac{2a^2+a^2bc-6abcS_0-2ab^2c^2S_0-8bcS_0^2-19b^2c^2S_0^2-6b^3c^3S_0^2}{4b(2+6bc+2b^2c^2)} \\
&\Pi^{SX} = \frac{2a^2+a^2bc-6abcS_0-2ab^2c^2S_0+5b^2c^2S_0^2+2b^3c^3S_0^2}{2b(2+6bc+2b^2c^2)}
\end{aligned}
\qquad (12)
$$

Proposition 2

If the producer can fix the prices before the importer fixes his taxes, this advantage will permit him to increase the prices with respect to the simultaneous case, obliging the importer to reduce the taxes. As a result, the price that the consumer pays will also be higher, and the quantities and the stock of pollution are reduced. The welfare of the consumers is also reduced and the cartel manages to increase its profits.

With respect to the case without taxes, similarly to the previous case, the producer´s prices, quantities, stock of pollution and profits of the cartel will be reduced, whilst the final price paid by the consumers and their welfare will increase.

Proof: See the Appendix.

3.4 Stackelberg. Leader: importers (SM)

Let us assume now that it is the importing country which decides first the taxes it is going to establish on the consumption of the resource, with the producer knowing this information at the time of the decision about the prices he fixes. In this case it will be the importers who, at the time to fix the taxes, will have to take into account the reaction of the producers to those taxes (incorporating the functions of best-response of the producers as a constraint at the time to maximize the welfare), in such a way that the problem of the government of the importing country will now be

$$\underset{\tau_1,\tau_2}{Max} W = u_1 + \tau_1 q_1 - \frac{1}{2}cS_1^2 + u_2 + \tau_2 q_2 - \frac{1}{2}cS_2^2$$

$$s.t \qquad p_1 = \frac{a - b\tau_1}{2b} \qquad p_2 = \frac{a - b\tau_2}{2b} \tag{13}$$

Solving this will give, in equilibrium

$$
\begin{aligned}
p_1^{SM} &= \frac{3a - 6bcS_0 - b^2c^2S_0}{9b + 9b^2c + b^3c^2} & \tau_1^{SM} &= \frac{3a + 9abc + ab^2c^2 + 12bcS_0 + 2b^2c^2S_0}{9b + 9b^2c + b^3c^2} \\
p_2^{SM} &= \frac{3a + abc - 3bcS_0}{9b + 9b^2c + b^3c^2} & \tau_2^{SM} &= \frac{3a + 7abc + ab^2c^2 + 6bcS_0}{9b + 9b^2c + b^3c^2} \\
q_1^{SM} &= \frac{3a - 6bcS_0 - b^2c^2S_0}{9 + 9bc + b^2c^2} & q_2^{SM} &= \frac{3a + abc - 3bcS_0}{9 + 9bc + b^2c^2} \\
S_1^{SM} &= \frac{3a + 9S_0 + 3bcS_0}{9 + 9bc + b^2c^2} & S_2^{SM} &= \frac{6a + abc + 9S_0}{9 + 9bc + b^2c^2} \\
W^{SM} &= \frac{6a^2 + a^2bc - 18abcS_0 - 2ab^2c^2S_0 - 18bcS_0^2 - 3b^2c^2S_0^2}{2b(9 + 9bc + b^2c^2)} \\
\Pi^{SM} &= \frac{18a^2 + 6a^2bc + a^2b^2c^2 - 54abcS_0 - 12ab^2c^2S_0 + 45b^2c^2S_0^2 + 12b^3c^3S_0^2 + b^4c^4S_0^2}{b(9 + 9bc + b^2c^2)^2}
\end{aligned}
\tag{14}
$$

Proposition 3

If the importing country performs as leader, in the second period it will set taxes higher than in the simultaneous case, forcing the producer to reduce his price. Admittedly the price that the consumer pays will increase, and consequently the quantity consumed of the resource in the second period will decrease. With respect to the first period, the relationship will depend on the values that the parameters take. As a result, an increase in the welfare of the importing country and a decrease in the profits of the cartel will take place.

With respect to the case in which the producer acts as leader, now the prices and the profits of the producer will be smaller, but the welfare in the importing country as well as the taxes will be higher, whilst the relation among the rest of the variables will depend on the value which the parameters take.

In relation to the case without taxes, in a similar way to the previous case, the prices of the producer, the quantities, the stock of pollution and the profits of the cartel will decrease, whilst the final price paid by the consumers and their welfare will increase.

Proof: See the Appendix.

3.5 Absence of environmental concern

In all the previous cases we have assumed that the importing country is worried by the environmental damage provoked by the consumption of the resource. However, it may happen that the government of the importing country claims not to know about the environmental problem (or the consumption of the resource does not generate environmental problems), in such a way that at the time to make decisions, the environmental damage is not taken into account. In this way, the objective function of the importing country will be modified, with the term that captures the environmental damage ($c=0$) disappearing. We are going to analyse how the decisions of the agents will change in each of the previous cases.

Proposition 4

Both in the simultaneous case and in the case in which the producer is the Stackelberg leader, the government of the importing country uses the taxes just to correct the environmental damage, without possibilities of using them strategicaly, and therefore if the environmental damage is not taken into account the taxes will be zero, and the results will be identical to the case without taxes. However, when the importing country is the Stackelberg leader, then it has the capacity to use the taxes strategicaly, in such a way that even if that government does not take into account the environmental damage, , the taxes will be positive. So, in this case the government of the importing country, as it fixes the taxes first, will force the exporting cartel to reduce its prices, and then the welfare of the importing country will increase and the profits of the cartel will decrease with respect to a situation without taxes. Indirectly, it also manages to reduce the environmental damage because it will increase the prices paid by the consumers, thus reducing the quantity of the resource consumed.

Proof: See the Appendix.

4. Consideration of the environmental damage by both producers and importers

Until now we have considered that only the importing country took into account the environmental damage provoked by the consumption of the resource. However, when we are faced with an environmental problem such as climate change, in which the location of the polluter has no relevance when the damage is determined, because the stock of greehouse gases affects all the planet independently of the place from which the emission took place, it may happen that the producer country is also concerned by the environmental damage provoked by the consumption of the resource he produces.

In this way, in this section we are going to assume that both exporters and importers are concerned by the environmental damage deriving from the consumption of the resource, in such a way that now the exporting country will not miximize its profits but its welfare, which is assumed to be equal to the profits minus the negative externality provoked by the stock of pollution.

4.1 Absence of taxes (SIA)

Now the problem of the producer cartel will be the following

$$\begin{aligned} \underset{p_1,p_2}{Max}\,\Pi = {} & p_1q_1 + p_2q_2 - \frac{1}{2}cS_1^2 - \frac{1}{2}cS_2^2 = p_1(a-bp_1) + p_2(a-bp_2) + \\ & -\frac{1}{2}c(S_0 + a - bp_1)^2 - \frac{1}{2}c(S_0 + a - bp_1 + a - bp_2)^2 \end{aligned} \tag{15}$$

Solving this problem we obtain that

$$\begin{aligned} & p_1^{SIA} = \frac{2a + 6abc + ab^2c^2 + 4bcS_0 + b^2c^2S_0}{4b + 6b^2c + b^3c^2} \qquad p_2^{SIA} = \frac{2a + 5abc + ab^2c^2 + 2bcS_0}{4b + 6b^2c + b^3c^2} \\ & q_1^{SIA} = \frac{2a - 4bcS_0 - b^2c^2S_0}{4 + 6bc + b^2c^2} \qquad q_2^{SIA} = \frac{2a + abc - 2bcS_0}{4 + 6bc + b^2c^2} \\ & S_1^{SIA} = \frac{2a + 4S_0 + 2bcS_0}{4 + 6bc + b^2c^2} \qquad S_2^{SIA} = \frac{4a + abc + 4S_0}{4 + 6bc + b^2c^2} \\ & W^{SIA} = \frac{8a^2 - 16a^2bc - 7a^2b^2c^2 - a^2b^3c^3 - 72abcS_0 - 24ab^2c^2S_0 - 32bcS_0^2}{2b(4 + 6bc + b^2c^2)^2} + \\ & + \frac{+4b^2c^2S_0^2 + 4b^3c^3S_0^2 + b^4c^4S_0^2}{2b(4 + 6bc + b^2c^2)^2} \\ & \Pi^{SIA} = \frac{16a^2 + 28a^2bc + 10a^2b^2c^2 + a^2b^3c^3 - 48abcS_0 - 80ab^2c^2S_0}{2b(4 + 6bc + b^2c^2)^2} + \\ & + \frac{-24ab^3c^3S_0 - 2ab^4c^4S_0 - 32bcS_0^2 - 56b^2c^2S_0^2 - 20b^3c^3S_0^2 - 2b^4c^4S_0^2}{2b(4 + 6bc + b^2c^2)^2} \end{aligned} \tag{16}$$

4.2 Taxes (IA)

If the government of the importing country establishes in each period a tax on the consumption of the resource, the problem of the producer cartel will now be

$$\underset{p_1,p_2}{Max}\,\Pi = p_1q_1 + p_2q_2 - \frac{1}{2}cS_1^2 - \frac{1}{2}cS_2^2 = p_1(a - bp_1 - b\tau_1) + p_2(a - bp_2 - b\tau_2)$$
$$-\frac{1}{2}c(S_0 + a - bp_1 - b\tau_1)^2 + -\frac{1}{2}c(S_0 + a - bp_1 - b\tau_1 + a - bp_2 - b\tau_2)^2 \quad (17)$$

Solving this maximization, we obtain the best-response functions of the cartel

$$p_1 = \frac{2a + 6abc + ab^2c^2 + 4bcS_0 + b^2c^2S_0 - 2b\tau_1 - 5b^2c\tau_1 - b^3c^2\tau_1 - b^2c\tau_2}{4b + 6b^2c + b^3c^2}$$
$$p_2 = \frac{2a + 5abc + ab^2c^2 + 2bcS_0 - b^2c\tau_1 - 2b\tau_2 - 4b^2c\tau_2 - b^3c^2\tau_2}{4b + 6b^2c + b^3c^2} \quad (18)$$

On the other hand, the importing country has exactly the same problem as in section 3,2, that is, at the time of defining its strategy about taxes it is not affected by the environmental concern of the producer. In this way, in equilibrium we will have that

$$p_1^{IA} = \frac{a}{2b} \qquad \tau_1^{IA} = \frac{3ac + abc^2 + 4cS_0 + 2bc^2S_0}{2 + 6bc + 2b^2c^2} \qquad q_1^{IA} = \frac{a - 4bcS_0 - 2b^2c^2S_0}{2 + 6bc + 2b^2c^2}$$
$$p_2^{IA} = \frac{a}{2b} \qquad \tau_2^{IA} = \frac{2ac + abc^2 + 2cS_0}{2 + 6bc + 2b^2c^2} \qquad q_2^{IA} = \frac{a + abc - 2bcS_0}{2 + 6bc + 2b^2c^2}$$
$$S_1^{IA} = \frac{a + 2S_0 + 2bcS_0}{2 + 6bc + 2b^2c^2} \qquad S_2^{IA} = \frac{2a + abc + 2S_0}{2 + 6bc + 2b^2c^2}$$
$$W^{IA} = \frac{2a^2 + a^2bc - 12abcS_0 - 4ab^2c^2S_0 - 8bcS_0^2 - 4b^2c^2S_0^2}{8b + 24b^2c + 8b^3c^2} \quad (19)$$
$$\Pi^{IA} = \frac{4a^2 + 9a^2bc + 6a^2b^2c^2 + a^2b^3c^3 - 24abcS_0 - 48ab^2c^2S_0}{2b(2 + 6bc + 2b^2c^2)^2} +$$
$$+\frac{-24ab^3c^3S_0 - 4ab^4c^4S_0 - 8bcS_0^2 - 8b^2c^2S_0^2 - 4b^3c^3S_0^2}{2b(2 + 6bc + 2b^2c^2)^2}$$

Therefore, we can see how the prices are now equal to the prices of the section 3.1 That is, the prices when taxes exist and the producers take into account the environmental damage are equal to the prices when taxes do not exist and the producers do not consider the environmental damage.

Proposition 5

When the producers take into account the environmental damage, the introduction of a tax by the importers reduces the prices of the producer, the consumed quantities and the stock of pollution and increases the prices paid by the consumers, whilst the welfare of the importers increases and the welfare of the exporters decreases.

Proof: See the Appendix.

4.3 Comparison with the case in which the producer has no environmental concern

To finish this section, we are going to compare the results obtained in this and in the previous section. First, it can be checked that the prices of the producer when the importer uses taxes are equal to the prices when there are no taxes and the producer has no environmental concern. Therefore, keeping in mind the previous propositions, when there are no taxes the prices will be higher if the producer has an environmental concern, and the same will happen if there are taxes. All things considered, the environmental concern of the producer provokes a general increase in the prices that the producer sets for the resource, in order to compensate for the environmental damage provoked by its consumption.

There exist other interesting relationships among the results which are obtained in both situations, that we present in the following propositions.

Proposition 6

When the producer is concerned by the environmental damage, if the importer does not establish taxes to correct it, the producer will accomplish that function, by increasing its prices up to the point in which consumption (and therefore the stock of pollution) is the same as when there is no environmental concern of the producers but there exists a tax established by the importer.

Proof: See the Appendix.

Proposition 7

The stock of pollution in each period will be smaller when the producer is also concerned by the environment, despite the fact that the taxes will be smaller than when no such environmental concern by the producer exists.

Proof: See the Appendix.

Proposition 8

When taxes exist, the welfare in the importing country will be higher if the producer does not have an environmental concern. If there are no taxes, the relationship will depend on the values that the parameters take.

With respect to the welfare in the exporting country, when there are no taxes, this will be smaller in the case in which the producer has an environmental concern, whilst if there are taxes, it will depend on the values that the parameters take.

Proof: See the Appendix.

5. Resumé and conclusions

In this work we have analysed the relationship between a cartel exporter of a natural resource and a country importer of such a resource, studying the influence of the taxes and the environmental concerns on the prices and the quantity consumed of such a resource, as well as on the stock of pollution and the level of welfare of exporters and importers. The main conclusions that we obtain are that the introduction of a tax in order to correct the environmental externality provoked by the consumption of the resource permits the prices of the producer and the consumed quantity of the resource to decline, reducing the level of pollution. Moreover, the welfare in the importing country is increased and the profits of the cartel are reduced.

If instead of being simultaneous, the decisions are sequential, in the case in which the exporter is the first in taking the decision, this will permit him to increase his prices and his benefits, forcing the importer to reduce his taxes, althouh as a final result the quantity consumed and the welfare of the importers will be reduced. If the importer acts as leader, in the second period he will set taxes higher than in the simultaneous case, forcing the producer to reduce his price. As a result, the price paid by the consumer will increase and, therefore the consumed quantity of the resource will be reduced. In the first period, the relationship will depend on the values that the parameters take, but as a consequence of what happens in both periods the welfare will increase and the profits of the cartel will fall.

Similarly, when the environmental damage is not incorporated into the decision making, only if the importer can set the taxes before the exporter fix the prices, will the importer be able to use these taxes in a strategic way in order to co-opt part of the profits of the cartel.

If the producer is also concerned by the environmental problem, then if the importer does not establish taxes it will be the exporter who corrects the environmental problem, increasing his prices in such a way that the quantity consumed will be the same as when the importer fixed taxes and the exporter disentangled himself from the environmental problem. If, in these circumstances, the importer also introduces taxes, the consumption of the resource will decline more and therefore, the stock of pollution. The welfare will increase in the importing country and will decrease in the exporting one. Anyway, the welfare in the importing country will be smaller than when the exporter was not concerned by the environmental problem.

In this work we do not consider the case in which the resource can present scarcity problems. A first extension of the work would take into account such a possibility, which would mean the incorporation of increasing extracting costs as the resource is being used. Also a rate of discount could be incorporated into the model.

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APPENDIX

Proof of Proposition 1

We have that

$$
\begin{aligned}
&p_1^I = p_1^{SI} + \frac{-6ac - abc^2 - 8cS_0 - 2bc^2S_0}{8+12bc+2b^2c^2} \qquad p_2^I = p_2^{SI} + \frac{-4ac - abc^2 - 4cS_0}{8+12bc+2b^2c^2} \\
&q_1^I = q_1^{SI} + \frac{-6abc - ab^2c^2 - 8bcS_0 - 2b^2c^2S_0}{8+12bc+2b^2c^2} \qquad q_2^I = q_2^{SI} + \frac{-4abc - ab^2c^2 - 4bcS_0}{8+12bc+2b^2c^2} \\
&p_1^I + \tau_1^I = p_1^{SI} + \frac{6ac + abc^2 + 8cS_0 + 2bc^2S_0}{8+12bc+2b^2c^2} \qquad p_2^I + \tau_2^I = p_2^{SI} + \frac{4ac + abc^2 + 4cS_0}{8+12bc+2b^2c^2} \\
&W^I = W^{SI} + \frac{80a^2c + 188a^2bc^2 + 200a^2b^2c^3 + 58a^2b^3c^4 + 5a^2b^4c^5 + 96acS_0 + 288abc^2S_0}{8(4+6bc+b^2c^2)^2} + \\
&+ \frac{+432ab^2c^3S_0 + 136ab^3c^4S_0 + 12ab^4c^5S_0 + 80bc^2S_0^2 + 240b^2c^3S_0^2 + 84b^3c^4S_0^2 + 8b^4c^5S_0^2}{8(4+6bc+b^2c^2)^2}
\end{aligned} \tag{A1}
$$

As a, b, c and S_0 are positive, with the introduction of the tax, the prices of the producer and the quantities are reduced, at the same time the price paid by the consumers and the welfare in the importing country increase. Moreover, as q_1 and q_2 are smaller than in the case without taxes, S_1 and S_2 will also be smaller. On the other hand, the prices and the quantities are smaller in both periods, with respect to the case without taxes, and therefore the profits of the producer will also be smaller.

Proof of Proposition 2

We have that

$$
\begin{aligned}
p_1^I &= p_1^{SX} + \frac{-6abc - ab^2c^2 + 10b^2c^2S_0 + 2b^3c^3S_0}{8b + 12b^2c + 2b^3c^2} = p_1^{SX} + \frac{(a - 2bcS_0)(-b^2c^2 - 6bc) - 2b^2c^2S_0}{8b + 12b^2c + 2b^3c^2} \\
p_2^I &= p_2^{SX} + \frac{-4abc - ab^2c^2 + 6b^2c^2S_0 + b^3c^3S_0}{8b + 12b^2c + 2b^3c^2} = p_2^{SX} + \frac{(a - 2bcS_0)(-b^2c^2 - 4bc) - 2b^2c^2S_0 - b^3c^3S_0}{8b + 12b^2c + 2b^3c^2} \\
q_1^I &= q_1^{SX} + \frac{6abc + 3ab^2c^2 - 10b^2c^2S_0 - 6b^3c^3S_0 - b^4c^4S_0}{(2 + 6bc + 2b^2c^2)(4 + 6bc + b^2c^2)} = \\
&= q_1^{SX} + \frac{(a - 2bcS_0 - b^2c^2S_0)(6bc + 3b^2c^2) + 2b^2c^2S_0 + 6b^3c^3S_0 + 2b^4c^4S_0}{(4 + 6bc + b^2c^2)(2 + 6bc + 2b^2c^2)} \\
q_2^I &= q_2^{SX} + \frac{4abc + 3ab^2c^2 + ab^3c^3 - 6b^2c^2S_0 - 3b^3c^3S_0}{(2 + 6bc + 2b^2c^2)(4 + 6bc + b^2c^2)} = \\
&= q_2^{SX} + \frac{(a - 2bcS_0)(4bc + 3b^2c^2) + 2b^2c^2S_0 + 3b^3c^3S_0 + ab^3c^3}{(2 + 6bc + 2b^2c^2)(4 + 6bc + b^2c^2)} \\
\tau_1^I &= \tau_1^{SX} + \frac{16abc^2 + 9ab^2c^3 + ab^3c^4 - 26b^2c^3S_0 - 15b^3c^4S_0 - 2b^4c^5S_0}{(2 + 6bc + 2b^2c^2)(4 + 6bc + b^2c^2)} = \\
&= \tau_1^{SX} + \frac{(a - 2bcS_0)(16bc^2 + 9b^2c^3 + b^3c^4) + 6b^2c^3S_0 + 3b^3c^4S_0}{(2 + 6bc + 2b^2c^2)(4 + 6bc + b^2c^2)} \\
\tau_2^I &= \tau_2^{SX} + \frac{10abc^2 + 6ab^2c^3 + ab^3c^4 - 16b^2c^3S_0 - 9b^3c^4S_0 - b^4c^5S_0}{(2 + 6bc + 2b^2c^2)(4 + 6bc + b^2c^2)} = \\
&= \tau_2^{SX} + \frac{(a - 2bcS_0)(10bc^2 + 6b^2c^3 + b^3c^4) + 4b^2c^3S_0 + 3b^3c^4S_0 + b^4c^5S_0}{(2 + 6bc + 2b^2c^2)(4 + 6bc + b^2c^2)}
\end{aligned}
\qquad \text{(A2)}
$$

$$W^{I} = W^{SX} + \frac{80a^2bc + 220a^2b^2c^2 + 140a^2b^3c^3 + 34a^2b^4c^4 + 3a^2b^5c^5}{2b(4+6bc+b^2c^2)^2(4+12bc+4b^2c^2)} +$$

$$+ \frac{-256ab^2c^2S_0 - 696ab^3c^3S_0 - 424ab^4c^4S_0 - 90ab^5c^5S_0 - 6ab^6c^6S_0}{2b(4+6bc+b^2c^2)^2(4+12bc+4b^2c^2)} +$$

$$+ \frac{+208b^3c^3S_0^2 + 568b^4c^4S_0^2 + 352b^5c^5S_0^2 + 79b^6c^6S_0^2 + 6b^7c^7S_0^2}{2b(4+6bc+b^2c^2)^2(4+12bc+4b^2c^2)} =$$

$$= W^{SX} + \frac{(a-2bcS_0)^2(80bc + 220b^2c^2 + 140b^3c^3 + 34b^4c^4 + 3b^5c^5)}{2b(4+6bc+b^2c^2)^2(4+12bc+4b^2c^2)} +$$

$$+ \frac{+(a-2bcS_0)(64b^2c^2S_0 + 184b^3c^3S_0 + 136b^4c^4S_0 + 46b^5c^5S_0 + 6b^6c^6S_0)}{2b(4+6bc+b^2c^2)^2(4+12bc+4b^2c^2)}$$

$$+ \frac{+16b^3c^3S_0^2 + 56b^4c^4S_0^2 + 64b^5c^5S_0^2 + 35b^6c^6S_0^2 + 6b^7c^7S_0^2}{2b(4+6bc+b^2c^2)^2(4+12bc+4b^2c^2)}$$

$$\Pi^{I} = \Pi^{SX} + \frac{-52a^2b^2c^2 - 40a^2b^3c^3 - 10a^2b^4c^4 - a^2b^5c^5}{2b(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)} +$$

$$+ \frac{+168ab^3c^3S_0 + 128ab^4c^4S_0 + 30ab^5c^5S_0 + 2ab^6c^6S_0}{2b(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)} +$$

$$+ \frac{-136b^4c^4S_0^2 - 104b^5c^5S_0^2 - 25b^6c^6S_0^2 - 2b^7c^7S_0^2}{2b(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)} =$$

(A3)

$$= \Pi^{SX} + \frac{(a-2bcS_0)^2(-52b^2c^2 - 40b^3c^3 - 10b^4c^4 - b^5c^5) + (a-2bcS_0)(-40b^3c^3S_0}{2b(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)} +$$

$$+ \frac{-32b^4c^4S_0 - 10b^5c^5S_0 - 2b^6c^6S_0) - 8b^4c^4S_0^2 - 8b^5c^5S_0^2 - 5b^6c^6S_0^2 - 2b^7c^7S_0^2}{2b(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)}$$

The parameters being positive and as $p_1^{SX} > 0 \Rightarrow (a-2bcS_0) > 0$ and $q_1^{SX} > 0 \Rightarrow (a-2bcS_0 - b^2c^2S_0) > 0$, we see how the prices of the producer are higher than in the simultaneous case, whilst the taxes are smaller. Moreover, the quantity is smaller in both periods, and therefore the price of the consumer in each period will be higher than in the simultaneous case. On the other hand, the welfare of the consumers diminishes with respect to the simultaneous case, whilst the profits of the cartel increase.

$$p_1^{SI} = p_1^{SX} + cS_0 \qquad p_2^{SI} = p_2^{SX} + \frac{cS_0}{2}$$

$$q_1^{SI} = q_1^{SX} + \frac{3abc + ab^2c^2 + 2bcS_0 + b^2c^2S_0}{2 + 6bc + 2b^2c^2} \qquad q_2^{SI} = q_2^{SX} + \frac{2abc + ab^2c^2 + bcS_0}{2 + 6bc + 2b^2c^2} \tag{A4}$$

$$W^{SI} = W^{SX} + \frac{-13a^2b^2c^2 - 5a^2b^3c^3 - 6abcS_0 - 34ab^2c^2S_0}{8b(1 + 3bc + b^2c^2)} +$$

$$+ \frac{-12ab^3c^3S_0 - 5b^2c^2S_0^2 - 2b^3c^3S_0^2}{8b(1 + 3bc + b^2c^2)}$$

As *a*, *b*, *c* and S_0 are positive, the prices and the quantities will be smaller than when taxes are not used, whilst the welfare will be greater. Moreover, as the quantities are smaller, the stock of pollution will also be smaller, whilst the prices that the consumers pay will be higher. Moreover, as prices and quantities are smaller, the profits of the producer will also be smaller.

Proof of Proposition 3

We obtain that

$$p_1^I = p_1^{SM} + \frac{6a - ab^2c^2 - 12bcS_0 - 5b^2c^2S_0 - b^3c^3S_0}{(4 + 6bc + b^2c^2)(9b + 9b^2c + b^3c^2)} =$$

$$= p_1^{SM} + \frac{2(3a - 6bcS_0 - b^2c^2S_0) - ab^2c^2 - 3b^2c^2S_0 - b^3c^3S_0}{(4 + 6bc + b^2c^2)(9b + 9b^2c + b^3c^2)}$$

$$p_2^I = p_2^{SM} + \frac{6a + 5abc + 2ab^2c^2 - 6bcS_0 + b^3c^3S_0}{(4 + 6bc + b^2c^2)(9b + 9b^2c + b^3c^2)} =$$

$$= p_2^{SM} + \frac{2(3a - 6bcS_0 - b^2c^2S_0) + 5abc + 2ab^2c^2 + 6bcS_0 + 2b^2c^2S_0 + b^3c^3S_0}{(4 + 6bc + b^2c^2)(9b + 9b^2c + b^3c^2)}$$

$$q_1^I = q_1^{SM} + \frac{6ab - ab^3c^2 - 12b^2cS_0 - 5b^3c^2S_0 - b^4c^3S_0}{(4 + 6bc + b^2c^2)(9 + 9bc + b^2c^2)} =$$

$$= q_1^{SM} + \frac{2b(3a - 6bcS_0 - b^2c^2S_0) - ab^3c^2 - 3b^3c^2S_0 - b^4c^3S_0}{(4 + 6bc + b^2c^2)(9 + 9bc + b^2c^2)}$$

$$q_2^I = q_2^{SM} + \frac{6ab + 5ab^2c + 2ab^3c^2 - 6b^2cS_0 + b^4c^3S_0}{(4 + 6bc + b^2c^2)(9 + 9bc + b^2c^2)} =$$

$$= q_2^{SM} + \frac{2b(3a - 6bcS_0 - b^2c^2S_0) + 5ab^2c + 2ab^3c^2 + 6b^2cS_0 + 2b^3c^2S_0 + b^4c^3S_0}{(4 + 6bc + b^2c^2)(9 + 9bc + b^2c^2)}$$

$$\tau_1^I = \tau_1^{SM} + \frac{-12a + 2ab^2c^2 + 24bcS_0 + 10b^2c^2S_0 + 2b^3c^3S_0}{(4 + 6bc + b^2c^2)(9b + 9b^2c + b^3c^2)} = \tag{A5}$$

$$= \tau_1^{SM} + \frac{-2[2(3a - 6bcS_0 - b^2c^2S_0) - ab^2c^2 - 3b^2c^2S_0 - b^3c^3S_0]}{(4 + 6bc + b^2c^2)(9b + 9b^2c + b^3c^2)}$$

As $p_1^{SM} > 0 \Rightarrow (3a - 6bcS_0 - b^2c^2S_0) > 0$, and the parameters are positive, we have that the price of the producer and the quantity in the second period will be smaller than in the simultaneous case. As the quantity in the second period is smaller, the price of the consumer will be higher, and as the price of the producer is smaller, the tax will be higher than in the simultaneous case. With respect to the first period, the price of the producer and the quantity will be smaller (or larger) if the following condition is satisfied (not satisfied)

$$2(3a - 6bcS_0 - b^2c^2S_0) > ab^2c^2 + 3b^2c^2S_0 + b^3c^3S_0 \qquad \text{(A6)}$$

If this condition holds (does not hold), the tax and the price of the consumer will be higher (smaller) than in the simultaneous case.

$$W^I = W^{SM} + \frac{-24a^2 - 16a^2bc - 7a^2b^2c^2 - 2a^2b^3c^3 + 72abcS_0 + 32ab^2c^2S_0}{2b(4+6bc+b^2c^2)^2(9+9bc+b^2c^2)} +$$

$$+ \frac{-2ab^4c^4S_0 - 60b^2c^2S_0^2 - 32b^3c^3S_0^2 - 7b^4c^4S_0^2 - b^5c^5S_0^2}{2b(4+6bc+b^2c^2)^2(9+9bc+b^2c^2)} =$$

$$= W^{SM} + \frac{(2a - 4bcS_0 - b^2c^2S_0)^2(-6) + (2a - 4bcS_0 - b^2c^2S_0)(-8abc}{2b(4+6bc+b^2c^2)^2(9+9bc+b^2c^2)} +$$

$$+ \frac{-3{,}5ab^2c^2 - 12bcS_0 - 6b^2c^2S_0) - 2a^2b^3c^3 - 12ab^2c^2S_0 - 22ab^3c^3S_0}{2b(4+6bc+b^2c^2)^2(9+9bc+b^2c^2)}$$

$$+ \frac{-5{,}5ab^4c^4S_0 - 12b^2c^2S_0^2 - 20b^3c^3S_0^2 - 7b^4c^4S_0^2 - b^5c^5S_0^2}{2b(4+6bc+b^2c^2)^2(9+9bc+b^2c^2)}$$

$$\Pi^I = \Pi^{SM} + \frac{360a^2 + 660a^2bc + 425a^2b^2c^2 + 174a^2b^3c^3 + 45a^2b^4c^4}{b(4+6bc+b^2c^2)^2(9+9bc+b^2c^2)^2} +$$

$$+ \frac{+4a^2b^5c^5 - 1080abcS_0 - 1752ab^2c^2S_0 - 720ab^3c^3S_0 - 48ab^4c^4S_0}{b(4+6bc+b^2c^2)^2(9+9bc+b^2c^2)^2} +$$

$$+ \frac{+30ab^5c^5S_0 + 4ab^6c^6S_0 + 900b^2c^2S_0^2 + 1536b^3c^3S_0^2 + 785b^4c^4S_0^2}{b(4+6bc+b^2c^2)^2(9+9bc+b^2c^2)^2} +$$

$$+ \frac{+198b^5c^5S_0^2 + 30b^6c^6S_0^2 + 2b^7c^7S_0^2}{b(4+6bc+b^2c^2)^2(9+9bc+b^2c^2)^2} =$$

$$= \Pi^{SM} + \frac{(2a - 4bcS_0 - b^2c^2S_0)^2(90+165bc) + (2a - 4bcS_0 - b^2c^2S_0)(212{,}5ab^2c^2 +}{b(4+6bc+b^2c^2)^2(9+9bc+b^2c^2)^2} +$$

$$+ \frac{+87ab^3c^3 + 22{,}5ab^4c^4 + 2ab^5c^5 + 180bcS_0 + 624b^2c^2S_0 + 165b^3c^3S_0)}{b(4+6bc+b^2c^2)^2(9+9bc+b^2c^2)^2} + \qquad \text{(A7)}$$

$$+ \frac{+460ab^3c^3S_0 + 512{,}5ab^4c^4S_0 + 207ab^5c^5S_0 + 34{,}5ab^6c^6S_0 + 2ab^7c^7S_0}{b(4+6bc+b^2c^2)^2(9+9bc+b^2c^2)^2} +$$

$$+ \frac{+180b^2c^2S_0^2 + 852b^3c^3S_0^2 + 659b^4c^4S_0^2 + 198b^5c^5S_0^2 + 30b^6c^6S_0^2 + 2b^7c^7S_0^2}{b(4+6bc+b^2c^2)^2(9+9bc+b^2c^2)^2}$$

With respect to the welfare and the profits, as $q_1^I = (2a - 4bcS_0 - b^2c^2S_0) > 0$, we see that an increase in the welfare of the importers is produced, with respect to the simultaneous case, and a reduction in the profits of the cartel.

$$
\begin{aligned}
&p_1^{SI} = p_1^{SM} + \frac{3a + 9abc + ab^2c^2 + 12bcS_0 + 2b^2c^2S_0}{18b + 18b^2c + 2b^3c^2} \\
&p_2^{SI} = p_2^{SM} + \frac{3a + 7abc + ab^2c^2 + 6bcS_0}{18b + 18b^2c + 2b^3c^2} \\
&q_1^{SI} = q_1^{SM} + \frac{3a + 9abc + ab^2c^2 + 12bcS_0 - 2b^2c^2S_0}{18 + 18bc + 2b^2c^2} \\
&q_2^{SI} = q_2^{SM} + \frac{3a + 7abc + ab^2c^2 + 6bcS_0}{18 + 18bc + 2b^2c^2} \\
&W^{SI} = W^{SM} + \frac{-6a^2 - 31a^2bc - 43a^2b^2c^2 - 5a^2b^3c^3 - 36abcS_0}{8b(1 + 3bc + b^2c^2)} + \\
&+ \frac{-100ab^2c^2S_0 - 12ab^3c^3S_0 - 60b^2c^2S_0^2 - 8b^3c^3S_0^2}{8b(1 + 3bc + b^2c^2)}
\end{aligned}
\qquad \text{(A8)}
$$

As *a*, *b*, *c* and S_0 are positive, the prices and the quantities will be smaller than when taxes are not used, whilst the welfare will be higher. Similarly, as the quantities are smaller, the stock of pollution wll also be smaller, whilst the prices that the consumers pay will be bigger. On the other hand , as the prices and quantities are smaller, the profits of the producer will also be smaller.

$$p_1^{SM} = p_1^{SX} + \frac{-3a - 9abc - ab^2c^2 + 6bcS_0 + 16b^2c^2S_0 + 2b^3c^3S_0}{18b + 18b^2c + 2b^3c^2} =$$
$$= p_1^{SX} + \frac{(a - 2bcS_0)(-3 - 9bc - b^2c^2) - 2b^2c^2S_0}{18b + 18b^2c + 2b^3c^2}$$
$$p_2^{SM} = p_2^{SX} + \frac{-3a - 7abc - ab^2c^2 + 3bcS_0 + 9b^2c^2S_0 + b^3c^3S_0}{18b + 18b^2c + 2b^3c^2} =$$
$$= p_2^{SX} + \frac{(a - 2bcS_0)(-3 - 7bc - b^2c^2) - 3bcS_0 - 5b^2c^2S_0 - b^3c^3S_0}{18b + 18b^2c + 2b^3c^2}$$
$$\tau_1^{SM} = \tau_1^{SX} + \frac{6a + 9abc + 26ab^2c^2 + 12ab^3c^3 + ab^4c^4 - 12bcS_0}{(9b + 9b^2c + b^3c^2)(2 + 6bc + 2b^2c^2)} +$$
$$+ \frac{-23b^2c^2S_0 - 49b^3c^3S_0 - 21b^4c^4S_0 - 2b^5c^5S_0}{(9b + 9b^2c + b^3c^2)(2 + 6bc + 2b^2c^2)} =$$
$$= \tau_1^{SX} + \frac{(a - 2bcS_0 - b^2c^2S_0)(6 + 9bc + 26b^2c^2 + 12b^3c^3 + b^4c^4)}{(9b + 9b^2c + b^3c^2)(2 + 6bc + 2b^2c^2)} +$$
$$+ \frac{+b^2c^2S_0 + 12b^3c^3S_0 + 29b^4c^4S_0 + 12b^5c^5S_0 + b^6c^6S_0}{(9b + 9b^2c + b^3c^2)(2 + 6bc + 2b^2c^2)}$$
$$\tau_2^{SM} = \tau_2^{SX} + \frac{6a + 14abc + 23ab^2c^2 + 9ab^3c^3 + ab^4c^4 - 6bcS_0}{(9b + 9b^2c + b^3c^2)(2 + 6bc + 2b^2c^2)} +$$
$$+ \frac{-9b^2c^2S_0 - 26b^3c^3S_0 - 12b^4c^4S_0 - b^5c^5S_0}{(9b + 9b^2c + b^3c^2)(2 + 6bc + 2b^2c^2)} = \tau_2^{SX} +$$
$$+ \frac{(a - 2bcS_0)(6 + 14bc + 23b^2c^2 + 9b^3c^3 + b^4c^4) + 6bcS_0}{(9b + 9b^2c + b^3c^2)(2 + 6bc + 2b^2c^2)} + \qquad \text{(A9)}$$
$$+ \frac{+19b^2c^2S_0 + 20b^3c^3S_0 + 6b^4c^4S_0 + b^5c^5S_0}{(9b + 9b^2c + b^3c^2)(2 + 6bc + 2b^2c^2)}$$
$$q_1^{SM} = q_1^{SX} + \frac{-3a + 9abc + 5ab^2c^2 + 6bcS_0 - 11b^2c^2S_0 - 7b^3c^3S_0 - b^4c^4S_0}{(9 + 9bc + b^2c^2)(2 + 6bc + 2b^2c^2)}$$
$$q_2^{SM} = q_2^{SX} + \frac{-3a + 2abc + 2ab^2c^2 + ab^3c^3 + 3bcS_0 - 9b^2c^2S_0 - 5b^3c^3S_0}{(9 + 9bc + b^2c^2)(2 + 6bc + 2b^2c^2)}$$

As the parameters are positive and as $p_1^{SX} > 0 \Rightarrow a > 2bcS_0$ y $q_1^{SX} > 0 \Rightarrow a > 2bcS_0 + b^2c^2S_0$, we see how the taxes are smaller and the prices of the producer are higher when the producer acts as leader than when he acts as follower. However, the prices paid by the consumers, and then the quantities consumed and the stock of pollution will depend on the values of the parameters.

With respect to the welfare and the profits, as was proved previously, $W^I > W^{SX}$ y $W^I < W^{SM}$, and then the welfare in the importing country will be higher when the importing country is leader, than when is a follower, whilst as also was proved $\Pi^{I} < \Pi^{SX}$ and $\Pi^{I} > \Pi^{SM}$, in such a way that the profits of the cartel will be greater when he acts as leader than when he acts as follower.

Proof of Proposition 4

In the previous results it can be seen clearly that if *c=0*, both in the simultaneous case and when the producer is the Stackelberg leader, the tax fixed by the government will be zero in both periods and therefore we obtain the same results as in the case with absence of taxes, that is, in this case[5]

$$\begin{array}{lll} p_1^{IN} = p_1^{SXN} = p_1^{SI} = \dfrac{a}{2b} & q_1^{IN} = q_1^{SXN} = q_1^{SI} = \dfrac{a}{2} & W^{IN} = W^{SXN} = W^{SIN} = \dfrac{a^2}{4b} \\ p_2^{IN} = p_2^{SXN} = p_2^{SI} = \dfrac{a}{2b} & q_2^{IN} = q_2^{SXN} = q_2^{SI} = \dfrac{a}{2} & \Pi^{IN} = \Pi^{SXN} = \Pi^{SI} = \dfrac{a^2}{2b} \end{array} \tag{A10}$$

However when the importing country is the Stackelberg leader, the taxes will be positive in both periods, in such a way that we obtain the following analytical solutions

$$\begin{array}{llll} p_1^{SMN} = \dfrac{a}{3b} & q_1^{SMN} = \dfrac{a}{3} & \tau_1^{SMN} = \dfrac{a}{3b} & W^{SMN} = \dfrac{a^2}{3b} \\ p_2^{SMN} = \dfrac{a}{3b} & q_2^{SMN} = \dfrac{a}{3} & \tau_2^{SMN} = \dfrac{a}{3b} & \Pi^{SMN} = \dfrac{2a^2}{9b} \end{array} \tag{A11}$$

Comparing, we see that

$$\begin{array}{lll} p_1^{SI} = p_1^{SMN} + \dfrac{a}{6b} & q_1^{SI} = q_1^{SMN} + \dfrac{a}{6} & W^{SIN} = W^{SMN} - \dfrac{a^2}{12b} \\ p_2^{SI} = p_2^{SMN} + \dfrac{a}{6b} & q_2^{SI} = q_2^{SMN} + \dfrac{a}{6} & \Pi^{SI} = \Pi^{SMN} + \dfrac{5a^2}{18b} \end{array} \tag{A12}$$

As all the parameters are positive, the prices of the producer and the quantities are smaller than in the case without taxes, whilst the welfare is higher and the profits of the cartel are smaller.

[5] In the notation, we add an *N* in the superindex of each case in order to avoid confusions with the previous sections. In the case without taxes, the results do not vary and therefore we mantained the original notation (with the exception of the welfare that is modified when the environmental damage is not taken into account).

Proof of Proposition 5

After some calculations we arrive at

$$
\begin{aligned}
p_1^{IA} &= p_1^{SIA} + \frac{-6ac - abc^2 - 8cS_0 - 2bc^2 S_0}{8 + 12bc + 2b^2c^2} \\
p_2^{IA} &= p_2^{SIA} + \frac{-4ac - abc^2 - 4cS_0}{8 + 12bc + 2b^2c^2} \\
q_1^{IA} &= q_1^{SIA} + \frac{-6abc - 3ab^2c^2 - 8bcS_0 - 6b^2c^2S_0 - 2b^3c^3S_0}{(4 + 6bc + b^2c^2)(2 + 6bc + 2b^2c^2)} \\
q_2^{IA} &= q_2^{SIA} + \frac{-4abc - 3ab^2c^2 - ab^3c^3 - 4bcS_0 + 2b^3c^3S_0}{(4 + 6bc + b^2c^2)(2 + 6bc + 2b^2c^2)} = \\
&= q_2^{SIA} + \frac{(2a + abc - 2bcS_0)(-b^2c^2) - 4abc - ab^2c^2 - 4bcS_0}{(4 + 6bc + b^2c^2)(2 + 6bc + 2b^2c^2)}
\end{aligned}
\tag{A13}
$$

$$W^{IA}=W^{SIA}+\frac{80a^2c+324a^2bc^2+220a^2b^2c^3+54a^2b^3c^4+5a^2b^4c^5}{4(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)}+$$

$$+\frac{+96acS_0+320abc^2S_0-144ab^2c^3S_0-224ab^3c^4S_0-60ab^4c^5S_0}{4(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)}$$

$$+\frac{-4ab^5c^6S_0-80bc^2S_0^2-480b^2c^3S_0^2-340b^3c^4S_0^2-84b^4c^5S_0^2-8b^5c^6S_0^2}{4(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)}=$$

$$=W^{SIA}+\frac{(a-4bcS_0-2b^2c^2S_0)(80ac+324abc^2+220ab^2c^3+54ab^3c^4}{4(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)}+$$

$$+\frac{+5ab^4c^5+96cS_0+640bc^2S_0+1312b^2c^3S_0+1304b^3c^4S_0)+304bc^2S_0^2}{4(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)}+$$

$$+\frac{+2272b^2c^3S_0^2+6188b^3c^4S_0^2+7756b^4c^5S_0^2+2600b^5c^6S_0^2+596ab^4c^5S_0}{4(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)}+$$

$$+\frac{+124ab^5c^6S_0+10ab^6c^7S_0}{4(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)}$$

$$\Pi^{IA}=\Pi^{SIA}+\frac{-160a^2c-712a^2bc^2-1112a^2b^2c^3-776a^2b^3c^4-271a^2b^4c^5}{2(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)^2}+$$

$$+\frac{-46a^2b^5c^6-3a^2b^6c^7-192acS_0-448abc^2S_0+384ab^2c^3S_0}{2(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)^2}+$$

$$+\frac{+1640ab^3c^4S_0+1368ab^4c^5S_0+472ab^5c^6S_0+72ab^6c^7S_0+4ab^7c^8S_0}{2(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)^2}+$$

$$+\frac{+480bc^2S_0^2+2032b^2c^3S_0^2+3080b^3c^4S_0^2+2120b^4c^5S_0^2+736b^5c^6S_0^2}{2(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)^2}+$$

$$+\frac{+124b^6c^7S_0^2+8b^7c^8S_0^2}{2(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)^2}=$$

$$=\Pi^{SIA}+\frac{(a-4bcS_0-2b^2c^2S_0)(-160ac-712abc^2-1112ab^2c^3-776ab^3c^4}{2(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)^2}+$$

$$+\frac{-271ab^4c^5-46ab^5c^6-3ab^6c^7-192cS_0-1088bc^2S_0-2784b^2c^3S_0}{2(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)^2}+$$

$$+\frac{-4232b^3c^4S_0-3960b^4c^5S_0-2164b^5c^6S_0)-654ab^6c^7S_0-100ab^7c^8S_0}{2(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)^2}+$$

$$+\frac{-6ab^8c^9S_0-288bc^2S_0^2-2704b^2c^3S_0^2-10232b^3c^4S_0^2-20376b^4c^5S_0^2}{2(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)^2} \qquad \text{(A14)}$$

$$+\frac{-23568b^5c^6S_0^2-16452b^6c^7S_0^2-4320b^7c^8S_0^2}{2(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)^2}$$

As *a*, *b*, *c* and S_0 are positive, and as $q_2^{SIA}>0\Rightarrow(2a+abc-2bcS_0)>0$, the prices of the producer and the quantities are smaller with the introduction of the tax. As the quantities are smaller, the price that the consumers pay will be higher than in absence of taxes and the stock of accumulated pollution in each period will be smaller.

Finally, as $q_1^{IA} > 0 \Rightarrow (a - 4bcS_0 - 2b^2c^2S_0) > 0$, with the introduction of the tax the welfare of the consumers will increase, and the welfare of the exporters will decrease.

Proof of proposition 6

$$\begin{aligned} p_1^I + \tau_1^I &= \frac{2a + 6abc + ab^2c^2 + 4bcS_0 + b^2c^2S_0}{4b + 6b^2c + b^3c^2} = p_1^{SIA} \\ p_2^I + \tau_2^I &= \frac{2a + 5abc + ab^2c^2 + 2bcS_0}{4b + 6b^2c + b^3c^2} = p_2^{SIA} \end{aligned} \tag{A15}$$

Proof of proposition 7

$$\begin{aligned} \tau_1^{IA} &= \tau_1^I + \frac{-16abc^2 - 9ab^2c^3 - ab^3c^4 - 20bc^2S_0 - 12b^2c^3S_0 - 2b^3c^4S_0}{(4 + 6bc + b^2c^2)(2 + 6bc + 2b^2c^2)} \\ \tau_2^{IA} &= \tau_2^I + \frac{-10abc^2 - 6ab^2c^3 - ab^3c^4 - 12bc^2S_0 - 6b^2c^3S_0}{(4 + 6bc + b^2c^2)(2 + 6bc + 2b^2c^2)} \\ p_1^{IA} + \tau_1^{IA} &= p_1^I + \tau_1^I + \frac{6abc + 3ab^2c^2 + 8bcS_0 + 6b^2c^2S_0 + 2b^3c^3S_0}{(4b + 6b^2c + b^3c^2)(2 + 6bc + 2b^2c^2)} \\ p_2^{IA} + \tau_2^{IA} &= p_2^I + \tau_2^I + \frac{4abc + 3ab^2c^2 + ab^3c^3 + 4bcS_0 - 2b^3c^3S_0}{(4b + 6b^2c + b^3c^2)(2 + 6bc + 2b^2c^2)} = \\ &= p_2^I + \tau_2^I + \frac{(2a + abc - 2bcS_0)(b^2c^2) + 4abc + ab^2c^2 + 4bcS_0}{(4b + 6b^2c + b^3c^2)(2 + 6bc + 2b^2c^2)} \end{aligned} \tag{A16}$$

As all the parameters are positive, and as $q_2^{SIA} > 0 \Rightarrow (2a + abc - 2bcS_0) > 0$, the taxes will be lower and the price paid by the consumers will be higher when the producer is concerned by the environmental problems. As the price paid by the consumers is higher, the consumed quantities will be smaller, and therefore the stock of pollution will also be small.

Proof of proposition 8

After some calculations, we arrive at

$$W^{SIA}=W^{SI}+\frac{-80a^2bc+124a^2b^2c^2+192a^2b^3c^3+58a^2b^4c^4}{8b(4+6bc+b^2c^2)^2}+$$
$$+\frac{+5a^2b^5c^5-96abcS_0+480ab^2c^2S_0+528ab^3c^3S_0+144ab^4c^4S_0}{8b(4+6bc+b^2c^2)^2}+$$
$$+\frac{+12ab^5c^5S_0+400b^2c^2S_0^2+368b^3c^3S_0^2+100b^4c^4S_0^2+8b^5c^5S_0^2}{8b(4+6bc+b^2c^2)^2}$$
$$W^{IA}=W^{I}+\frac{-80a^2bc-220a^2b^2c^2-140a^2b^3c^3-34a^2b^4c^4-3a^2b^5c^5}{4b(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)}+$$
$$+\frac{-96abcS_0-64ab^2c^2S_0+336ab^3c^3S_0+264ab^4c^4S_0+60ab^5c^5S_0}{4b(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)}$$
$$+\frac{+4ab^6c^6S_0+240b^2c^2S_0^2+608b^3c^3S_0^2+380b^4c^4S_0^2+92b^5c^5S_0^2+8b^6c^6S_0^2}{4b(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)}=$$
$$=W^{I}+\frac{(a-4bcS_0-2b^2c^2S_0)(-80abc-220ab^2c^2-140ab^3c^3-34ab^4c^4}{4b(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)}+$$
$$+\frac{-3ab^5c^5-96bcS_0-384b^2c^2S_0-704b^3c^3S_0-736b^4c^4S_0)}{4b(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)}+$$
$$+\frac{-356ab^5c^5S_0-76ab^6c^6S_0-6ab^7c^7S_0-144b^2c^2S_0^2-1120b^3c^3S_0^2}{4b(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)}+ \qquad \text{(A17)}$$
$$+\frac{-3204b^4c^4S_0^2-4260b^5c^5S_0^2-1464b^6c^6S_0^2}{4b(4+6bc+b^2c^2)^2(2+6bc+2b^2c^2)}$$

As $q_1^{IA}>0 \Rightarrow (a-4bcS_0-2b^2c^2S_0)>0$, the welfare of the importing country when there are taxes will be higher if the producers do not take into account the environmental damage. When taxes do not exist, the relationship will depend on the values of the parameters.

$$\Pi^{SIA} = \Pi^{SI} + \frac{-20a^2bc - 34a^2b^2c^2 - 11a^2b^3c^3 - a^2b^4c^4}{2b(4+6bc+b^2c^2)^2} +$$

$$+ \frac{-48abcS_0 - 80ab^2c^2S_0 - 24ab^3c^3S_0 - 2ab^4c^4S_0}{2b(4+6bc+b^2c^2)^2} +$$

$$+ \frac{-32bcS_0^2 - 56b^2c^2S_0^2 - 20b^3c^3S_0^2 - 2b^4c^4S_0^2}{2b(4+6bc+b^2c^2)^2}$$

$$\Pi^{IA} = \Pi^{I} + \frac{-80a^2bc - 200a^2b^2c^2 - 36a^2b^3c^3 + 80a^2b^4c^4 + 45a^2b^5c^5}{2b(8+36bc+46b^2c^2+18b^3c^3+2b^4c^4)^2} +$$

$$+ \frac{+10a^2b^6c^6 + a^2b^7c^7 - 192abcS_0 - 704ab^2c^2S_0 - 1248ab^3c^3S_0}{2b(8+36bc+46b^2c^2+18b^3c^3+2b^4c^4)^2} +$$

$$+ \frac{-1760ab^4c^4S_0 - 1272ab^5c^5S_0 - 448ab^6c^6S_0 - 72ab^7c^7S_0 - 4ab^8c^8S_0}{2b(8+36bc+46b^2c^2+18b^3c^3+2b^4c^4)^2} +$$

$$+ \frac{-128bcS_0^2 - 672b^2c^2S_0^2 - 1824b^3c^3S_0^2 - 2792b^4c^4S_0^2 - 1992b^5c^5S_0^2}{2b(8+36bc+46b^2c^2+18b^3c^3+2b^4c^4)^2} +$$

$$+ \frac{-688b^6c^6S_0^2 - 116b^7c^7S_0^2 - 8b^8c^8S_0^2}{2b(8+36bc+46b^2c^2+18b^3c^3+2b^4c^4)^2} \qquad \text{(A18)}$$

As all the parameters are positive, the welfare in the exporting country when there are no taxes will be higher if there is no environmental concern in that country, whilst when there are taxes the relationship will depend on the values that the parameters take.

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