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International trade and environmental corporate social responsibility

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ABSTRACT

This paper analyzes firms' incentives to engage in environmental corporate social responsibility (ECSR) in an international market under imperfect competition. We find that in the absence of environmental taxes firms do not adopt ECSR. However, the implementation of environmental taxes by governments encourages firms to adopt ECSR under local damage. Consumers, producers, and environmentalists are better off if firms decide to be environmentally responsible than if they decide not to. We also find that the decision to adopt ECSR depends on transboundary pollution. Under global damage firms engage in ECSR only if they are highly concerned about the environment. This means that the existence of transboundary pollution negatively affects the incentives of firms to be environmentally friendly. Finally, we find that when governments cooperatively determine their environmental taxes, firms engage in ECSR under both local and global damage. Thus, under global damage firms have greater incentives to be environmentally friendly when governments cooperate on environmental policies than when they do not.

1. Introduction

Since the 1990s concern among governments about the quality of the environment has led them to implement policies to control pollution. For many decades, the standard solution to environmental problems has taken the form of environmental laws and regulations imposed by governments (see Barrett, 1994; Ulph, 1996; Markusen, 1997; Requate, 2006; Bárcena-Ruiz and Garzón, 2014; Bárcena-Ruiz and Campo, 2017; Ino and Matsumura, 2021). The two instruments of environmental policy most widely used by developed countries are environmental taxes and standards (see, for example, Helfand, 1999). By using these instruments, governments try to get firms to internalize the damage generated by their pollutant emissions. In the absence of environmental policies, firms have no incentive to internalize that damage, so they are unlikely to abate emissions. Environmental studies have tended to consider that firms reduce emissions due to environmental policies set by countries that force them to do so.

More recently, alternative ways of achieving environmental protection have attracted widespread attention. Voluntary environmental programs have been used to attain a variety of environmental objectives such as reducing hazardous waste, increasing energy efficiency and cutting greenhouse gases (see Potoski and Prakash, 2005; Ericsson, 2006; Borck and Coglianese, 2009). These programs encourage voluntary actions by firms to improve their environmental performance beyond mere compliance.[1] Over the last few years corporate social responsibility (CSR) has been defined as a concept whereby companies decide voluntarily to contribute to a better society and a cleaner environment (European Commission, 2001; Kitzmueller and Shimshack, 2012).[2] Voluntary actions by firms to address environmental problems fall within the so-called environmental corporate social responsibility

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[1] Arora and Cason (1995) argue that there is a growing trend in developed countries for firms to reduce emission levels beyond the level required by law. They point out that over 1200 firms took part in the EPA's 33/50 program, agreeing to voluntarily reduce certain chemical emissions by 50% by 1995. There is also evidence that toxic emissions by firms decreased by 43% from 1988 to 1997 even though they were not directly regulated (Anton et al., 2004). Hirose et al. (2020) point out that in 2014, 26 major firms from different industrial sectors in Korea voluntarily declared that they would reduce fine dust emissions.

[2] In fact, CSR has become an important business strategy and there is increasing empirical evidence that firms engage in CSR activities. This has attracted increasing attention from researchers. KPMG (2017) reviews corporate social responsibility and sustainability reporting by a large number of companies in 49 countries. Factors other than the environment that influence CSR include privatization policies (Kim et al., 2019; Dong and Bárcena-Ruiz, 2021b), unionized labor (Fanti and Buccella, 2019), R&D investments (Dong and Bárcena-Ruiz, 2021a; Wang, 2021), cross-ownership (Bárcena-Ruiz and Sagasta, 2021a), and the strategic use of CSR (Planer-Friedrich and Sahm, 2020).

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(ECSR). Lu et al. (2019) point out that European governments are trying to promote ECSR because it can help to implement countries' environmental policy objectives on a voluntary basis. They comment on various public policies that help to promote ECSR, such as awards, taxes, directives and regulations, training information campaigns, and online platforms. They argue that public policies to promote ECSR can deliver positive results in implementing the sustainable development goals of countries. The European Union is the most active international organization in the development of government CSR programs. Albareda et al. (2007) point out that CSR has now become a priority issue on government agendas.[3]

One relevant issue for study is why profit-maximizing firms take voluntary actions to address environmental problems. Lu et al. (2019) argue that although many attempts have been made to define the determinants of ECSR, it is still unclear what the main reason is for firms to engage in ECSR. Hirose et al. (2020) discuss several reasons. First, they point out that ECSR may be connected with the reputation of firms (Liu et al., 2015). Indeed, there are empirical papers which show that the financial performance of firms that care about ECSR is relatively higher (see Margolis et al., 2007).[4] Second, self-regulation can be used to prevent the government from imposing regulations (Maxwell et al., 2000; Antweiler, 2003). Third, firms may adopt voluntary actions to avoid pressure from activists (Baron, 2001). Finally, Coluccia et al. (2018) and Campbell (2007) point out that the CSR behavior of firms is affected by institutional factors such as cultural traits, the rule of law, regulations, and the presence of institutionalized norms on CSR disclosure.[5]

In recent years, more and more papers have studied the environmental policies implemented by governments, assuming that firms care about social concerns. Some of those studies measure CSR concerns through the consumer surplus, so the objective function of a consumer-friendly firm is a convex combination of the consumer surplus and its profit (see Bárcena-Ruiz and Sagasta, 2021b; García et al., 2018; Leal et al., 2018, 2019; Xu and Lee, 2018). In those studies, the objective function of the firms therefore does not take into account their pollutant emissions. The papers in question analyze how the fact that firms care about the consumer surplus affects the environmental policies of governments. Other contributions have considered that socially responsible firms not only take into account their own profits but also incorporate environmental damage as part of their social concern (Lambertini and Tampieri, 2015; Lee and Park, 2019; Hirose et al., 2020; Fukuda and Ouchida, 2020). However, none of these papers takes into account that firms compete in international markets. Several papers consider the link between international markets and CSR firms, but they deal with trade policy rather than environmental policy (Xu and Lee, 2019; Wang et al., 2012; Fanti and Buccella, 2020; Chang et al., 2014). Our paper thus contributes to the literature by extending the knowledge of environmental policies in international markets when firms can adopt ECSR strategies. This enables us to analyze the incentives of firms to be environmentally friendly when governments use emission taxes as their environmental policy instrument, an issue that has not been analyzed by environmental economic literature.

In analyzing whether firms adopt ECSR strategies, this paper assumes an international single market framework comprising two countries whose governments set up environmental taxes to protect the environment. There is one firm located in each country and their production process, which presents constant returns to scale, gives rise to pollution. We analyze two cases: We assume first that environmental damage is limited to the country where the production takes place (local damage); and second that pollution from one country fully spills over to the other (global damage). Each government sets an environmental tax for its country, and taxes can be decided cooperatively or non-cooperatively.

Next we present our findings. As a benchmark, we consider that governments do not implement environmental policies and that firms can voluntarily decide to reduce emissions. Reducing emissions is costly and voluntary, so firms do not adopt ECSR with either local or global damage. This result is also obtained by Hirose et al. (2020) under quantity competition, assuming a single country whose firms commit to stay below a certain upper limit of emissions. They also show that if the decision to engage in ECSR is taken by an industry association, firms adopt ECSR because it serves as a collusive device that restricts their output.

The lack of environmental regulation means that firms have no incentive to adopt ECSR, so we analyze next whether the implementation of environmental taxes by governments may encourage them to be environmentally friendly. First, we consider that governments set taxes non-cooperatively. Under local damage, we find that in equilibrium both firms engage in ECSR. It is easy to see that firms do not adopt ECSR if there is only one country with two firms and the government implements environmental taxes. Therefore, it is the strategic interaction between governments that changes the result, encouraging firms to adopt ECSR.

Under local damage we find that a country whose firm adopts ECSR sets lower taxes than a country with a profit-maximizing firm. A lower tax encourages environmentally friendly firms to produce more, but their concern for the environment leads them to produce less. The former effect dominates so the output of an environmentally friendly firm is higher than that of a profit-maximizing firm. Despite this higher production, its higher level of abatement leads it to emit less pollution. Thus, it results that consumers, producers, and environmentalists are better off if the firms in both countries decide to be environmentally responsible than if they maximize profits. Compared to the case without environmental policies, we find that the implementation of environmental taxes encourages firms to adopt ECSR strategies. Therefore, a tax policy not only leads firms to abate emissions to reduce the tax burden but also promotes voluntary ECSR, which leads firms to further reduce emissions.

We also analyze whether the decision to be environmentally friendly depends on transboundary pollution. Under global damage, firms only engage in ECSR and therefore voluntarily abate emissions if their concern for environmental damage is high enough. Firms are better off being environmentally friendly, but consumers would only be in favor of it if firms are not excessively concerned about the environment (since it would reduce production). We obtain the counterintuitive result that environmentalists would prefer firms not to adopt ECSR, as it causes more environmental damage. This is because voluntarily reducing emissions leads firms to pay lower taxes and abate less than profit-maximizing firms. Therefore, being environmentally friendly when the concern of firms about ECSR is sufficiently high can be understood as a strategic behavior used by firms to obtain greater profits at the expense of the environment. Finally, social welfare is lower when firms are environmentally friendly.

Comparing the results obtained under local and global damage, we find that the existence of transboundary pollution affects the incentives of firms to be environmentally friendly. Firms adopt ECSR for a greater range of values of ECSR concern under local damage than under global damage. If ECSR concern is great enough, the two firms adopt ECSR with

[3] Boulouta and Pitelis (2014) consider a sample of developed countries and find that CSR-based positioning strategies can be important for national competitiveness and hence should be promoted by national initiatives.

[4] There is indirect evidence. Lioui and Sharma (2012) find that ECSR fosters the R&D efforts of firms, which generates additional value for them. Chuang and Huang (2018) find that ECSR has significant positive effects on green information technology capital, which has positive effects on environmental performance and business competitiveness. The results obtained by Wu et al. (2020) support an indirect effect of ECSR on financial performance through the strengthening of technological capability.

[5] There are studies that find a positive relationship between strong institutions and CSR penetration (Dhaliwal et al., 2012). García-Sánchez et al. (2016) examine the CSR performance of firms in 20 developed countries and show that companies in countries with a strong institutional environment make all efforts to ensure CSR disclosure.

both local and global damage. However, if firms care little about the environment, they adopt ECSR only under local damage.

Next, we consider that governments set environmental taxes cooperatively. We find that both firms engage in ECSR under both local and global damage. This implies that under global damage cooperation between governments encourages firms to be environmentally friendly for a greater range of ECSR concern values than when governments do not cooperate. Under local damage the same result is obtained in both cases. Therefore, cooperation in environmental policies by govermnents generates no less incentive for firms to be environmentally friendly than non-cooperation.[6]

Finally, we analyze whether the results of the paper hold in the following cases: (i) When the decision by firms in the first stage as to whether or not to engage in ECSR is made taking into account their objective function instead of profits; (ii) when there are decreasing returns to scale; and (iii) under price competition.

The rest of the paper is organized as follows: Section 2 introduces the model. Section 3 considers whether firms adopt ECSR or not when governments do not set environmental policies. Sections 4 and 5 analyze the decisions of firms whether or not to adopt ECSR when governments act non-cooperatively under local and global damage respectively. Section 6 analyzes the case in which the governments coordinate their environmental policies. Section 7 analyzes the following extensions of the main model: (i) The case when firms decide whether or not to engage in ECSR without strategic consideration; (ii) case when firms are faced with decreasing returns to scale; and (iii) price competition. Finally, Section 8 contains some concluding remarks.

2. The model

We consider a world market in which there are two countries, indexed by 1 and 2, with one firm in each country. The two firms are identical, produce a homogeneous good and compete freely in the world market. There are no transportation costs, and consumers from different countries cannot be discriminated.

Following Bárcena-Ruiz and Campo (2012), we assume that the inverse demand function of country i is given by $p = A - 2y_i$, where p is the world market price and y_i denotes the output sold in country i. The inverse demand function from the world market is given by $p = A - q_i - q_j$, where q_i denotes the output that firm i sells on the world market, and $q_i + q_j = y_i + y_j$ ($i \neq j$; $i, j = 1, 2$). With homogeneous consumers and no transportation costs between countries, a single market price prevails. Production takes place at constant returns to scale, where c is the marginal cost of production, which is identical for both firms.

Firms are engaged in Cournot competition, and their production process releases environmentally damaging emissions. Each unit of output produced causes one unit of pollutant emissions. The production of each firm causes pollution in its home country but may also affect the other country.

Governments and firms are concerned about maintaining the quality of the environment. To that end, the government of country i (government i) implements an environmental tax, t_i, per unit of pollution. Firms can prevent pollution by carrying out abatement activities. We denote by a_i the abatement level of firm i, so its total emission level is given by $e_i = q_i - a_i$. Abating emissions entails a positive cost, which is given by $C(a_i) = a_i^2$. The environmental damage function of country i is quadratic in the total emission level and is given by $ED_i = g(e_i + se_j)^2$, where s measures the extent to which emissions produced in country j spill over to country i (transboundary spillovers). Specifically, $s = 0$ means that each firm's emissions only damage the environment of its own country (local damage), while $s = 1$ means that emissions cause the same damage in both countries (global damage). Parameter g measures the valuation of the environment by government i; it can be interpreted as willingness to pay to decrease environmental damage by one unit. The total taxes collected by government i are $T_i = t_i e_i$.

The profits of firm i are given by:

$$\pi_i = (p - c)q_i - t_i(q_i - a_i) - a_i^2, i \neq j; i, j = 1, 2. \quad (1)$$

We assume that each firm cares about the pollution in its own country. Therefore, the objective function of firm i is given by:

$$V_i = \pi_i - \alpha ED_i, i \neq j; i, j = 1, 2. \quad (2)$$

αED_i can be interpreted as measuring the cost of factoring environmental considerations into all business activities, such as product design, manufacturing, supply, and distribution. Parameter α, which is assumed equal for both firms, denotes the weight that firm i places on environmental damage in addition to its profits and thus represents the degree of ECSR. Hence, $\alpha = 0$ means that the owner of firm i is only concerned about its profit and the higher parameter α is, the greater the concern of firm i for environmental damage is. The weight attached to environmental damage by firm i, α, is exogenous, with $\alpha \in [0, 1/2]$.[7]

The social welfare considered by government i includes the profits of firm i, the consumer surplus of domestic consumers, the total taxes collected by the government in country i, and the environmental damage in that country:

$$W_i = \pi_i + CS_i + T_i - ED_i, i = 1, 2. \quad (3)$$

As usual, the consumer surplus is given by $CS_i = (y_i)^2$, $i = 1, 2$. As the two countries are identical, this means that each obtains half of the total consumer surplus.

As is well-known, long-term variables that will affect the behavior of firms and governments in the coming years are set up before short-term ones that are decided just for a short period of time. The decision by governments as to whether to establish an environmental policy is a long-term decision that has been implemented by most developed countries. The decision by firms as to whether to be environmentally friendly or not is also a long-term decision since it is a determining factor in the way that firms will act over the coming years and thus part of the corporate culture of those firms. Short-term decisions taken by governments and firms, respectively, are the specific environmental taxes and the degree to which firms are environmentally friendly (considered exogenous in our model). Therefore, in our model, firms decide whether to be environmentally friendly or not before the optimal tax is chosen by the government.

We consider a four-stage game with the following timing. In the first stage the two firms simultaneously announce whether or not they will be engaging in ECSR. We assume that firms choose whether to engage in CSR or not for strategic reasons. That is, a firm adopts CSR if it increases its profits. Therefore, in the first stage, the profits of the firm are taken into account when making its decision. This is an approach found in recent papers such as Planer-Friedrich and Sahm (2020) and Bárcena-Ruiz and Sagasta (2021b). This approach enables us to analyze whether firms care about the environment because it increases their profits. In Section 7.1 this assumption is relaxed and firms' decision as to whether or not to adopt ECSR without strategic consideration is analyzed. There are four subgames, which can be reduced to three by symmetry. These subgames are the following: (i) both firms are concerned with ECSR (denoted by superscript *YY*); (ii) neither firm adopts ECSR (denoted by superscript *NN*); and (iii) one firm engages in ECSR activities while the

[6] The main results of the paper hold if quantity competition with heterogeneous products is assumed.

[7] It is generally not credible to think that firms adopting ECSR rules take environmental damage fully into account. When $\alpha > 1/2$ it can be obtained that the taxes set by governments and the emissions of firms are negative, which leads to corner solutions. This makes the presentation of the results cumbersome. Thus, without loss of generality, we assume that $\alpha \in [0, 1/2]$ to simplify the presentation of results. When $\alpha > 1/2$ the same result is obtained for whether firms engage in ECSR or not than when $\alpha = 1/2$.

other firm maximizes profits (superscript *YN* denotes the firm that engages in ECSR while *NY* denotes the firm that does not). In the second stage, governments decide their environmental taxes either cooperatively or non-cooperatively. In the non-cooperative case, each government decides what environmental tax will maximize the welfare of its own country. In the cooperative case, the two countries set the environmental taxes that maximize their joint welfare.[8] In the third stage, the firms independently and simultaneously choose abatement levels to maximize their objective functions. Finally, in the fourth stage, firms choose their output levels. The solution concept used is that of a subgame perfect Nash equilibrium in pure strategies. Therefore, the solutions are derived by backward induction from the last stage of the game. To simplify the presentation of the results we assume without loss of generality that $g = 2$.[9]

As a reference, and in order to make the contribution of the paper clearer, we first consider the situation in which governments do not set environmental policies and firms can voluntarily decide whether to reduce emissions. This enables us to analyze the incentives of the firms to adopt ECSR without the distortion caused by the strategic behavior of governments when they set environmental taxes. We also begin by analyzing the case in which the damage is local ($s = 0$).[10]

3. Governments do not implement environmental policies and there is local damage

Governments do not implement environmental policies and therefore do not set taxes, so $t_i = 0$, $i = 1, 2$. This means that the game has no second stage. We consider first that both firms engage in ECSR. In the fourth stage, each firm chooses the production level, q_i, that maximizes V_i given by (2). Solving this problem, we find that the equilibrium output of firm i is:

$$q_i = \frac{(A-c)(1+4\alpha) - 4\alpha a_j + 8\alpha(1+2\alpha)a_i}{(3+16\alpha+16\alpha^2)}, i \neq j; i,j = 1,2 \tag{4}$$

In the third stage, each firm chooses the abatement level, a_i, that maximizes V_i given by (2), taking into account (4). The superscript *YY* denotes the case where both firms adopt ECSR. Due to the symmetry of the model, we drop the subscript when we refer to firm i. Solving, we obtain the following:

$$a^{YY} = \frac{8(A-c)\alpha(1+2\alpha)}{9+60\alpha+80\alpha^2}, q^{YY} = \frac{(A-c)(3+16\alpha+16\alpha^2)}{9+60\alpha+80\alpha^2}$$

$$\pi^{YY} = \frac{(A-c)^2\left(9+132\alpha+576\alpha^2+960\alpha^3+512\alpha^4\right)}{\left(9+60\alpha+80\alpha^2\right)^2},$$

$$V^{YY} = \frac{(A-c)^2\left(9+114\alpha+480\alpha^2+832\alpha^3+512\alpha^4\right)}{\left(9+60\alpha+80\alpha^2\right)^2}$$

$$W^{YY} = \frac{4(A-c)^2\alpha\left(33+200\alpha+368\alpha^2+192\alpha^3\right)}{\left(9+60\alpha+80\alpha^2\right)^2}, i = 1,2 \tag{5}$$

Firms care about the environment, so they produce less and abate more as parameter α increases ($\partial q^{YY}/\partial\alpha < 0$, $\partial a^{YY}/\partial\alpha > 0$). As a result, firms generate lower emissions as their concern for the environment increases.

The equilibrium results for the case in which neither firm is environmentally friendly, denoted by superscript *NN*, are obtained by substituting $\alpha = 0$ in (5).

Next, we consider that firm i adopts ECSR while firm j maximizes its profits. In the fourth stage, firm i chooses q_i to maximize V_i given by (2), whereas firm j chooses q_j to maximize π_j given by (1). Solving these problems, the following emerges:

$$q_i = \frac{A-c+8a_i\alpha}{3+8\alpha}, q_j = \frac{(A-c)(1+4\alpha)-4a_i\alpha}{3+8\alpha}, i \neq j, i,j = 1,2 \tag{6}$$

In the third stage, firm i chooses a_i to maximize V_i whereas firm j chooses a_j to maximize π_j, taking into account (6). Solving, the following emerges:

$$a^{YN} = \frac{8(A-c)\alpha}{9+48\alpha}, a^{NY} = 0, q^{YN} = \frac{(A-c)(3+8\alpha)}{9+48\alpha}, q^{NY} = \frac{(A-c)(3+20\alpha)}{9+48\alpha},$$

$$\pi^{YN} = \frac{(A-c)^2(3+28\alpha+32\alpha^2)}{3(3+16\alpha)^2}, \pi^{NY} = \frac{(A-c)^2(3+20\alpha)^2}{9(3+16\alpha)^2},$$

$$V^{YN} = \frac{(A-c)^2(1+2\alpha)}{9+48\alpha}$$

Firm j does not abate emissions because it is not environmentally friendly and governments do not set taxes. Firm i cares about the environment, so its production decreases and its abatement level increases with parameter α. This gives firm j a competitive advantage, so it produces more than its rival ($q^{NY} > q^{YN}$) and makes higher profits ($\pi^{NY} > \pi^{YN}$).

Finally, we solve the first stage of the game, where firms decide whether or not to engage in ECSR. Solving this stage we obtain the following result.

Proposition 1. Under local damage, when governments do not implement environmental policies, in equilibrium neither firm engages in ECSR.[11]

It is easy to see that $\pi^{NN} > \pi^{YN}$ and $\pi^{NY} > \pi^{YY}$, so it is a dominant strategy for firms not to adopt ECSR. As a firm that engages in ECSR internalizes environmental damage, it produces less, abates more emissions and faces higher costs than a profit-maximizing firm. This places it at a strategic disadvantage to its rival. Under Cournot competition, output decisions are strategic substitutes, so if one firm produces less (due, for example, to a strategic disadvantage) its rival reacts by producing more, gaining market share and profits. As a result, if the rival firm does not engage in ECSR the optimal response is to follow suit ($\pi^{NN} > \pi^{YN}$), and if the rival firm adopts ECSR the optimal response is not to do so ($\pi^{NY} > \pi^{YY}$). This means that in equilibrium neither firm adopts ECSR, so they do not reduce emissions voluntarily. In addition, we find that $\pi^{YY} > \pi^{NN}$ if and only if $\alpha < 0.3170$. This represents a prisoner's dilemma for low values of environmental friendliness by firms, because both firms would benefit if both engaged in ECSR, but in equilibrium neither does.

This is the same result obtained by Hirose et al. (2020). They consider that firms from a single country adopt an emission cap that commits them to remain within a set upper limit of emissions (ECSR). They show that under quantity competition firms do not adopt ECSR. However, they accept ECSR coordinated by an industry association because it serves as a collusive device that restricts their output, resulting in a higher price. This leads to greater social welfare.

In our case, given that $\pi^{YY} > \pi^{NN}$ if and only if $\alpha < 0.3170$, the

[8] We consider that the governments can commit to an announced environmental policy. This occurs, for example, when they wish to comply with their announced policies or in the framework of binding international climate agreements to reduce emissions that cause global warming when countries are expected to fulfill those agreements.

[9] It can be shown that the main results of the paper hold for values of parameter g other than 2 for $g > 1$. When parameter g is low enough the valuation of the environment by governments and firms is also low, so firms adopt ECSR.

[10] The consideration of an additional parameter, s, which measures transboundary pollution, makes the model more cumbersome to resolve, so we begin by analyzing the case in which $s = 0$ and then study how the results change for $s = 1$. By undertaking simulations we find that the results obtained for $s = 0$ ($s = 1$) hold when s is low (high) enough.

[11] It can be seen that this result holds when environmental damage is global ($s = 1$).

industry profit is greater when firms adopt ECSR if α is low enough. This is because firms produce less when they adopt ECSR ($q^{YY} < q^{NN}$) and the increase in abatement costs is small (a^{YY} increases and q^{YY} decreases with α), so the profit of industry is greater when firms adopt ECSR. If $\alpha > 0.3170$, as parameter α is high enough, the increase in the cost of abating emissions when firms engage in ECSR is strong now so $\pi^{YY} < \pi^{NN}$. However, we obtain that $W^{YY} > W^{NN}$ so welfare is greater if the two firms engage in ECSR than if they do not care for the environment.

The lack of environmental regulation means that firms have no incentive to adopt ECSR, so it is interesting to analyze whether the implementation of environmental taxes by governments encourages firms to adopt ECSR.[12]

4. Environmental policy and local damage

This section analyzes the decision by firms of whether or not to engage in ECSR when environmental damage is local ($s = 0$) and governments do not cooperate when setting their environmental policies.

First we consider that both firms adopt ECSR. In the fourth stage, each firm chooses the production level, q_i, that maximizes V_i given by (2). Solving this problem, we obtain that the equilibrium outputs of each firm are:

$$q_i = \frac{(A-c)(1+4\alpha) + t_j - 2(1+2\alpha)t_i - 4\alpha a_j + 8\alpha(1+2\alpha)a_i}{3+16\alpha+16\alpha^2}, i \neq j; i,j = 1,2 \tag{7}$$

In the third stage, each firm chooses the abatement level, a_i, which maximizes V_i given by (2), taking into account (7). Solving, we obtain:

$$a_i = \begin{array}{l} 16\alpha(1+2\alpha)\left((A-c)(3+34\alpha+104\alpha^2+96\alpha^3)+\left(3+16\alpha+16\alpha^2\right)t_j\right) \\ -(27+336\alpha+1456\alpha^2+2688\alpha^3+1792\alpha^4)t_i/(2(1+2\alpha) \\ (27+432\alpha+2352\alpha^2+5120\alpha^3+3840\alpha^4)) \end{array} \tag{8}$$

Expressions (7) and (8) show that, given the tax chosen by government j, an increase in the tax set by government i reduces production and increases the abatement level in country i ($\partial q_i/\partial t_i < 0$, $\partial a_i/\partial t_i > 0$), which reduces total emissions in that country ($\partial e_i/\partial t_i < 0$). However, it increases production and abatement levels in country j ($\partial q_j/\partial t_i > 0$, $\partial a_j/\partial t_i > 0$), which increases total emissions in that country ($\partial e_j/\partial t_i > 0$).[13]

In the second stage, each government independently and simultaneously decides the optimal environmental tax that maximizes its social welfare, given by (3), taking as given the tax of the other country and the equilibrium behavior of the firms in the previous stages. Solving the problems, we obtain that the optimal tax set by each country is the following:

$$t^{YY} = \begin{array}{l} 8(A-c)(1+2\alpha)(81+1089\alpha+4992\alpha^2+7744\alpha^3-5632\alpha^4 \\ -26880\alpha^5-19456\alpha^6)/F \end{array} \tag{9}$$

where F=2349 + 41436α + 290496α^2 + 1037120α^3 + 1990144α^4 + 1950720α^5 + 765952α^6. It can be shown that environmental taxes are strategic complements. This means that if government i increases (decreases) its optimal environmental tax, government j follows suit. Moreover, the optimal environmental tax set by each government is decreasing in α. This is because greater concern about ECSR by firms leads them to reduce their output and emissions so the government sets lower taxes.

Lemma 1 *Under local damage, when firms adopt ECSR the equilibrium values of output, profits, each country's consumer surplus, environmental damage, the objective function, and social welfare are*:

$$q^{YY} = 3(A-c)(1+4\alpha)(3+4\alpha)\left(63+792\alpha+3440\alpha^2+6144\alpha^3+3840\alpha^4\right)/F,$$

$$\pi^{YY} = (A-c)^2(1+4\alpha)(3+4\alpha)\left(142155+4343868\alpha+58465584\alpha^2 + 457316928\alpha^3+2308730112\alpha^4+7892764672\alpha^5+18621386752\alpha^6 + 30256070656\alpha^7+33064026112\alpha^8+23011524608\alpha^9+9088008192\alpha^{10} + 1514143744\alpha^{11}\right)/F^2,$$

$$CS^{YY} = 9(A-c)^2(1+4\alpha)^2(3+4\alpha)^2\left(63+792\alpha+3440\alpha^2+6144\alpha^3 +3840\alpha^4\right)^2/F^2,$$

$$ED^{YY} = 2(A-c)^2(1+4\alpha)^2(3+4\alpha)^2\left(81+996\alpha+4256\alpha^2+7616\alpha^3 +4864\alpha^4\right)^2/F^2,$$

$$V^{YY} = \left((A-c)^2\left(426465+15187986\alpha+243009072\alpha^2+2311036704\alpha^3 + 14560743168\alpha^4+64104734208\alpha^5+202563321856\alpha^6+464105324544\alpha^7 + 768489553920\alpha^8+903773552640\alpha^9+727828135936\alpha^{10} + 374717022208\alpha^{11}+107474845696\alpha^{12}+12113149952\alpha^{13}\right)\right)/F^2,$$

$$W^{YY} = 12(A-c)^2(1+4\alpha)(3+4\alpha)\left(21870+657315\alpha+8663004\alpha^2 + 65946528\alpha^3+321254784\alpha^4+1047026432\alpha^5+2313664512\alpha^6 + 3425509376\alpha^7+3254992896\alpha^8+1794310144\alpha^9+436207616\alpha^{10}\right)/F^2.$$

The equilibrium results for the case in which neither firm is environmentally-friendly are obtained by substituting $\alpha = 0$ in (9) and in Lemma 1.

Next, we consider that firm i undertakes ECSR activities whereas firm j is a profit-maximizer. In the fourth stage, firm i chooses q_i to maximize V_i given by (2) while firm j chooses q_j to maximize π_j given by (1). Solving these problems, the following emerges:

$$q_i = \frac{A-c+t_j-2t_i+8\alpha a_i}{3+8\alpha}, q_j = \frac{(A-c)(1+4\alpha)-2(1+2\alpha)t_j+t_i-4\alpha a_i}{3+8\alpha} \tag{10}$$

In the third stage, firm i chooses a_i so as to maximize V_i whereas firm j chooses a_j so as to maximize π_j, taking into account (10). Solving, the following emerges:

$$a_i = \frac{16\left(A-c+t_j\right)\alpha(1+2\alpha)+(9+16\alpha)t_i}{6(3+22\alpha+32\alpha^2)}, a_j = \frac{t_j}{2} \tag{11}$$

An increase in t_i leads firm i to abate more, but the abatement level of firm j does not change since it is chosen for efficiency reasons. However, an increase in t_j increases a_i since it is chosen for strategic reasons.

In the second stage, both governments simultaneously and non-cooperatively choose the optimal taxes that maximize their own social welfare, given by (3). We denote the equilibrium values for firm i (j) by YN (NY). Solving, the following emerges:

$$\begin{array}{l} t^{YN} = \dfrac{4(A-c)(1+2\alpha)(7614+41787\alpha-13152\alpha^2-156736\alpha^3)}{110403+1056744\alpha+3101712\alpha^2+2895104\alpha^3} \\ t^{NY} = \dfrac{4(A-c)(7614+72027\alpha+206988\alpha^2+188480\alpha^3)}{110403+1056744\alpha+3101712\alpha^2+2895104\alpha^3} \end{array} \tag{12}$$

We find that environmental taxes are decreasing in α ($\partial t^{YN}/\partial\alpha < 0$and $\partial t^{NY}/\partial\alpha < 0$). As firm i reduces its emissions with α, the tax set by government i decreases with this parameter. In addition, given that taxes are strategic complements, the tax set by government j also decreases with parameter α. We find that $t^{NY} > t^{YN}$ because the firm that adopts ECSR produces less and generates lower emissions than the profit-maximizing firm. This case never appears in equilibrium, so the equilibrium results

[12] There may be other reasons, as mentioned in the introduction but not discussed in the paper, such as the incentive to raise a reputation, self-regulation or pressure from activists, which may lead firms to adopt ECSR.

[13] From (7) and (8) it emerges that $\partial(q_j - a_j)/\partial t_i = (3+8\alpha)(3+16\alpha+\alpha^2)/((1+2\alpha)(27+432\alpha+2352\alpha^2+5120\alpha^3+3840\alpha^4)) > 0$.

of this stage are relegated to Appendix A.

Finally, we solve the first stage of the game, where firms decide whether or not to engage in ECSR. A comparison of the optimal profits of firm i in Lemma 1, Lemma 1 for $\alpha = 0$, and Appendix A reveals that $\pi^{YN} > \pi^{NN}$ and $\pi^{YY} > \pi^{NY}$. Therefore, it is a dominant strategy for firms to engage in ECSR, so in equilibrium both firms are environmentally friendly. This result is shown in Proposition 2.

Proposition 2. Under local damage, when taxes are set non-cooperatively, in equilibrium both firms engage in ECSR.

Optimal emission taxes set by governments induce the social optimum through a combination of different effects. In a closed economy with imperfectly competitive firms, optimal environmental taxes take into account underproduction due to firms' market power and pollution costs. In an open economy, additional effects arise: First, the rent-seeking effect reduces equilibrium taxes, so the domestic firm can gain a competitive advantage over its rival. Second, with local damage the pollution-shifting effect raises equilibrium taxes, as an increase in the tax reduces domestic production and increases foreign production, shifting its associated pollution to the foreign country. Finally, the taxes set by the governments are also influenced by the degree of ECSR of the firms. As shown above a firm that adopts ECSR reduces its emissions with α, so the tax set by the government where the firm is located decreases with this parameter (ECSR effect).

Taking into account the above effects we find that, given the environmental preference of the rival firm, a country with a firm that adopts ECSR sets lower taxes than a country with a profit-maximizing firm: $t^{Nk} > t^{Yk}$, $k = N, Y$. This is because the first and third effects dominate the second one. A lower tax encourages environmentally friendly firms to produce more, but their concern for the environment leads them to reduce their production. The former effect dominates, so the output of an environmentally friendly firm is higher than that of a profit-maximizer, regardless of the environmental preference of the rival firm ($q^{Yk} > q^{Nk}$, $k = N, Y$).[14] In addition, denote by $I_i = (p - c)q_i$ the net income of firm i. Thus, a higher output by environmentally friendly firms implies a higher net income ($I^{Yk} > I^{Nk}$, $k = N, Y$). Greater production leads environmentally friendly firms to abate more: $a^{Yk} > a^{Nk}$, $k = N, Y$. The higher output produced by firms that adopt ECSR means that they emit more pollution ($e^{Yk} > e^{Nk}$, $k = N, Y$), although the total taxes paid by them are lower than those of profit-maximizing firms ($t^{Yk}e^{Yk} < t^{Nk}e^{Nk}$, $k = N, Y$). Environmentally friendly firms earn higher profits than profit-maximizing firms ($\pi^{Yk} > \pi^{Nk}$, $k = N, Y$) because their higher net income and lower total taxes paid more than offset higher abatement costs. Unlike the case without taxes, firms that adopt ECSR obtain a competitive advantage over profit-maximizing firms, and gain market share and profits since output decisions are strategic substitutes.

The asymmetric case in which just one firm adopts ECSR never occurs in equilibrium, so we next compare the social welfare components obtained when the two firms adopt ECSR with those obtained when neither of them does. From Lemma 1, Lemma 1 for $\alpha = 0$, and Appendix A, the following emerges.

Proposition 3. Under local damage, when taxes are set non-cooperatively, in equilibrium $\pi^{YY} > \pi^{NN}$, $CS^{YY} > CS^{NN}$, $ED^{YY} < ED^{NN}$ and $W^{YY} > W^{NN}$.

When the two firms adopt ECSR their production is higher than when they do not do so ($q^{YY} > q^{NN}$) because environmental taxes are lower ($t^{YY} < t^{NN}$). This leads firms to obtain greater net incomes in the former case ($I^{YY} > I^{NN}$). Environmentally friendly firms produce more and pay lower taxes, but because they care about environmental damage they abate more and emit less pollution than profit-maximizing firms($a^{YY} > a^{NN}, e^{YY} < e^{NN}$). Therefore, environmental damage is lower when both firms adopt ECSR. The higher production and net incomes when firms engage in ECSR mean higher profits and a greater consumer surplus. This implies that when the firms of both countries are environmentally friendly the producer and consumer surpluses are higher and environmental damage is lower than when they are profit-maximizers, resulting in greater social welfare. Therefore, under local damage consumers, producers, and the environment will all be better off if the firms in both countries are environmentally responsible.

As shown by Proposition 1 when governments do not implement environmental policies, in equilibrium neither firm engages in ECSR. However, Proposition 2 shows that when taxes are set non-cooperatively by governments, in equilibrium both firms adopt ECSR. The only difference between these two cases is that an environmental policy is implemented in the latter case. Therefore, comparing the results obtained in Propositions 1 and 2 leads to the following conclusion.

Proposition 4. Under local damage, when taxes are set non-cooperatively, the fact that governments implement environmental policies encourages firms to adopt ECSR.

Proposition 4 implies that the implementation of environmental policies when environmental damage is local is a factor that encourages firms to voluntarily adopt ECSR. This leads to an increase in social welfare in both countries.

Next, we analyze whether the results change when global damage is considered.

5. Environmental policy and global damage

This section examines the decision of firms whether or not to engage in ECSR when environmental damage is global ($s = 1$) and governments do not cooperate when setting their environmental policies. This case is resolved in a way similar to the case of local damage, so we relegate the computations to Appendix B. In this case, solving the first stage where both firms decide whether or not to engage in ECSR results in the following.

Proposition 5. Under global damage, when taxes are set non-cooperatively, in equilibrium neither firm engages in ECSR if $\alpha < 0.1239$ but both firms adopt ECSR if $\alpha > 0.1239$.

If $\alpha < 0.1239$ it follows that $\pi^{YN} < \pi^{NN}$ and $\pi^{YY} < \pi^{NY}$, so it is a dominant strategy for firms not to engage in ECSR. Thus, there is only one Nash equilibrium: neither firm engages in ECSR. If $\alpha > 0.1239$ it follows that $\pi^{YN} < \pi^{NN}$ and $\pi^{YY} > \pi^{NY}$, so there are two Nash equilibriums: in one both firms adopt ECSR and in the other both firms maximize profits. There are multiple Nash equilibriums, so Payoff Dominance is used to choose between them. This means that one equilibrium is chosen over others if it offers each player at least as much payoff as the other Nash equilibriums and is therefore Pareto superior to all other Nash equilibriums in the game. Comparing the profits of the firms when both adopt ECRS and when both maximize profits, it emerges that $\pi^{NN} < \pi^{YY}$, so the first equilibrium Pareto dominates the second and both firms prefer to engage in ECSR.

As in the case of local damage, under global damage when parameter α is low enough ($\alpha < 0.1239$), given the environmental preference of the rival firm, a country with a firm that adopts ECSR sets lower taxes than a country with a profit-maximizing firm ($t^{Yk} < t^{Nk}$, $k = Y, N$). A lower tax leads the environmentally friendly firm to produce more, but its concern for the environment means that it produces less. The latter effect is higher under global damage than under local damage due to strong transboundary spillovers. Therefore, under global damage and if α is slightly high, the latter effect dominates the former. This means that, contrary to what happens under local damage, the firm produces more if it decides to maximize profits than if it becomes environmentally friendly, obtaining greater net income and profits. As a result, when $\alpha <$

[14] Given that goods are substitutes, when just one firm adopts ECSR the environmentally friendly firm takes advantage of the lower taxes that it has to pay to gain market share and profits at the expense of the profit-maximizing firm.

0.1239, in equilibrium neither firm adopts ECSR.

When $\alpha > 0.1239$, the greater concern of the firms for the environment and the fact that environmental damage is global lead jointly to a non-interior solution in some of the cases considered.[15] When only one firm undertakes ECSR activities, that firm abates all its emissions, which is costly but which means that it is not affected by the tax set by its government. Its rival firm, which maximizes profits, takes advantage of this to gain market share, producing more than the environmentally friendly firm. However, the environmental tax does not affect the firm that adopts ECSR, so the rival firm's government may set the optimal tax on its local firm because there is no strategic interaction between governments when setting taxes. This reduces its profits. As a result, if one firm adopts ECSR its rival follows suit. In addition, if one firm does not engage in ECSR neither does its rival, since adopting ECSR implies abating all emissions, which is costly. This means that the production of the rival firm is higher when it does not engage in ECSR than when it does, resulting in higher net income and profits. When $\alpha > 0.2657$ there is no need for the government to set positive taxes when both firms engage in ECSR due to the firms' concern about the environment. If one firm adopts ECSR the output of its rival is higher when it maximizes profits than when it engages in ECSR, but it has to pay taxes so its abatement level is higher, increasing its cost and reducing its profits. Thus, if one firm engages in ECSR its rival follows suit. In addition, when a firm does not engage in ECSR its rival produces more and abates less if it does not adopt ECSR than if it does, resulting in higher profits. Therefore, there are two Nash equilibriums: in one of them both firms adopt ECSR and in the other both firms maximize profits. The first equilibrium Pareto dominates the second since firms pay higher taxes when they maximize profits, which leads them to obtain lower profits than when they adopt ECSR.

From the results shown in Appendix B the following emerges.

Proposition 6. Under global damage, when taxes are set non-cooperatively, in equilibrium $\pi^{YY} > \pi^{NN}$, $CS^{YY} > CS^{NN}$ *if and only if* $\alpha < 0.2848$, $ED^{YY} > ED^{NN}$ and $W^{YY} < W^{NN}$.

The optimal taxes set by the governments are lower when both firms engage in ECSR than when they do not. This is because, under global damage, environmentally friendly firms internalize part of the environmental damage when making production decisions. Lower taxes provide those firms that adopt ECSR with less incentive to abate. However, the fact that they take environmental damage into account encourages them to abate more. Since environmental damage is global, the first effect dominates (as taxes are higher than with local damage), which means that if both firms adopt ECSR they abate less than if they maximize profits. However, they produce more (so the consumer surplus is greater) only if $\alpha < 0.2848$.[16] All of this leads firms that adopt ECSR to generate more environmental damage. In addition, firms that adopt ECSR abate less and pay lower taxes, so they obtain higher profits. Finally, social welfare is greater when neither firm engages in ECSR due to the greater environmental damage caused by firms that adopt ECSR. Therefore, although with global damage firms are better off being environmentally friendly, consumers would be in favor of it only if firms do not care excessively about the environment (since this would reduce production). Finally, we obtain the counterintuitive result that environmentalists would prefer firms not to adopt ECSR, as it causes more environmental damage. This is because by voluntarily reducing emissions firms pay lower taxes, which means that they abate less than profit-maximizing firms. Therefore, being environmentally friendly when the damage is global and α is high enough can be a strategic behavior used by firms to obtain greater profits at the expense of the environment.

A comparison of the results of Propositions 5 and 6 reveals that being a profit-maximizing firm generates greater social welfare only if $\alpha < 0.1239$. However, if $\alpha > 0.1239$ firms adopt ECSR but governments prefer them not to do so. When α is low enough ($\alpha < 0.1239$), firms do not adopt ECSR so they pay higher taxes than environmentally friendly firms would. As a result, they produce less by being profit-maximizing firms, obtaining lower profits but generating less environmental damage and greater welfare. When α is high enough, firms adopt ECSR and obtain higher profits. However, the greater environmental damage leads to lower welfare.

Proposition 2 shows that under local damage both firms engage in ECSR. However, Proposition 5 shows that under global damage both firms engage in ECSR only if parameter α is high enough ($\alpha > 0.1239$). A comparison of the results in Propositions 2 and 5 leads to the following conclusion.

Proposition 7. When taxes are set non-cooperatively, firms adopt ECSR for a greater range of values of parameter α under local damage than under global damage.

Proposition 7 implies that the existence of transboundary pollution affects the incentives for firms to be environmentally friendly. Firms are environmentally friendly for a greater range of values of parameter α under local damage than under global damage. If $\alpha > 0.1239$ both firms adopt ECSR with both local and global damage. However, if the firms care little about the environment (i.e. if $\alpha < 0.1239$), both firms adopt ECSR only under local damage.

6. Cooperative taxes

In this section we assume that governments set their environmental taxes cooperatively to maximize the joint welfare of the two countries. We denote this case by a cap (circumflex accent mark). The third and fourth stages are the same as when taxes are set non-cooperatively, so the results of the previous sections apply. In the second stage, governments decide the optimal environmental taxes that maximize joint welfare. The results of this stage are relegated to Appendix D; from them we obtain the following result.

Proposition 8. Under both local and global damage, when taxes are set cooperatively, in equilibrium both firms engage in ECSR.

In the cooperative case governments coordinate their decisions on environmental taxes. This eliminates the strategic interaction between governments when they set taxes (so the rent-seeking effect and the pollution-shifting effect no longer exist), which increases equilibrium taxes compared to the non-cooperative case. As in the non-cooperative case, governments take into account the behavior of firms that adopt ECSR when they choose environmental taxes (ECSR effect), so taxes are lower for environmentally friendly firms than for profit-maximizing firms. This means that an environmentally friendly firm produces more than a profit-maximizing one for a given preference about the environment of the other firm. This is because the increase in production of a firm that adopts ECSR due to a lower environmental tax is greater than the reduction in production due to its environmental friendliness. As a result, a firm that adopts ECSR obtains greater profits than a profit-maximizing firm for a given preference about the environment of the other firm ($\pi^{Nk} < \pi^{Yk}$, $k = N, Y$). This in turn means that in equilibrium both firms adopt ECSR.

A comparison of Propositions 5 and 7 leads to the following conclusion.

[15] A corner solution is obtained if $\alpha > 0.1082$ when only one firm adopts ECSR. In this case, all emissions generated by the environmentally friendly firm are abated, so $e^{YN} = 0$. There is also a corner solution when both firms adopt ECSR for $\alpha > 0.2657$, since the optimal taxes set by the governments are zero $t^{YY} = 0$. There is no need for positive taxation because firms care enough about the environment.

[16] Paying a lower tax leads firms that adopt ECSR to produce more; those firms produce less as α increases. This means that for $\alpha > 0.2657$ governments with firms that adopt ECSR set zero taxes. This in turn means that the tax cannot be reduced as α increases, so for a sufficiently large value of α ($\alpha > 0.2848$) the output of profit-maximizing firms is greater than that of firms that adopt ECSR.

Proposition 9. Under global damage, cooperation between the two governments in setting environmental taxes encourages firms to adopt ECSR for a greater range of values of parameter α than when governments do not cooperate.

Under global damage, for low levels of environmental concern at firms ($\alpha < 0.1239$), when taxes are set non-cooperatively neither firm engages in ECSR, but while both firms adopt ECSR if taxes are set cooperatively. If $\alpha > 0.1239$ firms engage in ECSR in both cases. Therefore, under global damage cooperation between governments in setting environmental taxes encourages firms to adopt ECSR for a greater range of values of parameter α than when governments do not cooperate. However, under local damage firms adopt ECSR whether governments cooperate or not.

7. Extensions

7.1. Whether or not to engage in ECSR without strategic consideration

We analyze the decision of the two firms in the first stage as to whether or not to engage in ECSR, but we now consider that the firms take their objective functions, given by expression (2), into account when making their decisions. This is the approach used, for example, by Kopel and Brand (2012), Matsumura and Ogawa (2014), Chang et al. (2014), and Dong and Bárcena-Ruiz (2021a). Table 1 summarizes each firm's payoffs in each case.[17]

Comparing the payoffs of the firms, the results shown in Propositions 1 to 4 are found to hold under local damage both when governments do not implement environmental taxes and when they implement taxes non-cooperatively.

Under global damage, when governments set up environmental taxes non-cooperatively it emerges that $V^{YN} < \pi^{NN}$ and $V^{YY} < \pi^{NY}$. Therefore, the dominant strategy for firms is not to engage in ECSR for all values of α. This means that the results of Propositions 5 and 7 change. In this case, the following emerges: (i) Under global damage, in equilibrium neither firm engages in ECSR when taxes are set non-cooperatively; (ii) Firms adopt ECSR for a greater value of parameter α under local damage but not under global damage.

The above result leads to the following intuition: When a firm considers its objective function V_i instead of its profits, the value of adopting ECSR is lower, since $V_i = \pi_i - \alpha ED_i$. This leads to a weakening of the incentive to adopt ECSR when firms take into account V_i. When the damage is local ($s = 0$), since the value of ED_i is not high, the difference between π_i and V_i is small, so the results of Propositions 2 and 4 do not change. Under global damage ($s = 1$), when governments set environmental taxes cooperatively the results (Propositions 8 and 9) do not change either, because countries take into account the damage caused by the two firms when setting taxes, so the environmental damage is not great. However, under global damage, when governments set environmental taxes non-cooperatively each government takes into account the damage in its own country when setting the tax, which makes the environmental damage very large. With the damage being greater than under local damage, the incentives of firms to engage in ECSR are reduced, so they prefer not to do so regardless of whether the rival firm engages or not.

Table 1
Firms' payoffs.

		Firm 2	
		Y	N
Firm 1	Y	V^{YY}, V^{YY}	V^{YN}, π^{NY}
	N	π^{NY}, V^{YN}	π^{NN}, π^{NN}

[17] When there are corner solutions, the payoff matrix is similar, placing the optimal payoffs obtained in the corner solutions given by Appendixes B and D.

7.2. Decreasing returns to scale

To demonstrate the robustness and generality of our results, in this Section we consider the scenario in which firms are faced with decreasing returns to scale. We now consider that the cost function of firm i is $C(q_i) = q_i^2$, $i = 1, 2$. In this case, it can be shown that the main results hold.[18] Specifically, it is found that under local damage, when governments implement taxes non-cooperatively or cooperatively, in equilibrium both firms engage in ECSR regardless of whether the decision of each on whether or not to adopt ECSR is made on the basis of its profits or its objective function. Therefore, the results obtained in these cases do not change when a different production technology is considered. The results also hold in the case of global damage when governments cooperate in setting their environmental policies.

Under global damage, in equilibrium neither firm engages in ECSR if taxes are set non-cooperatively and each firm's decision on whether or not to adopt ECSR is made on the basis of its profits. However, if the decision is made on the basis of their objective functions V_i, the following emerges: in equilibrium neither firm engages in ECSR if $\alpha < 0.1679$ but both firms adopt ECSR if $\alpha > 0.1679$. Therefore, in equilibrium neither firm adopts ECSR when the parameter α is somewhat high, but greater concern by firms for the environment leads them to engage in ECSR. This means that the main result also holds.

7.3. Price competition

In this section we analyze whether the results of the paper hold under price competition. To that end, we assume that there is a continuum of consumers of the same type and the representative consumer maximizes $U(q_1,q_2) - p_1q_1 - p_2q_2$, where $q_i \geq 0$ is the amount of the good i and p_i is its price ($i = 1, 2$). The function $U(q_1,q_2)$ is given by:

$$U(q_1, q_2) = a\,(q_1 + q_2) - \frac{1}{2}\left(q_1^2 + 2bq_1q_2 + q_2^2\right), 1 > b > 0,$$

where parameter b measures the degree to which goods are substitutes.

Solving the problem of the representative consumer leads to the following inverse demand functions: $p_i = a - q_i - bq_j$, $i \neq j$; $i, j = 1, 2$. Thus, demand functions are given by:

$$q_i = \frac{a(1-b) - p_i - bp_j}{1 - b^2}, \mathrm{i} \neq j; i, j = 1, 2.$$

The profit of firm i is given by: $\pi_i = (p_i - c)\, q_i$. Consumer surplus is given by:

$$CS = U(q_1, q_2) - p_1q_1 - p_2q_2 = \frac{2a(1-b)(a - p_1 - p_2) + p_1^2 - 2bp_1p_2 + p_2^2}{2\left(1 - b^2\right)}.$$

The timing of the game is similar to that of quantity competition. The only difference is that now firms choose prices rather than quantities in the last stage. The resolution of the game in each of the cases considered is also similar so we omit it.[19] We present only the results for the case in which firms decide whether to engage in ECSR for strategic reasons since those for when the decision is taken considering the objective function given by (2) are similar. To simplify the presentation of the results obtained in this case we assume without loss of generality that $\alpha = 0.2$.[20]

We consider first that governments do not implement environmental taxes. Under local damage ($s = 0$) we find that $\pi^{NN} > \pi^{YN}$ for all b, $\pi^{YY} >$

[18] Computations are available from the authors on request.

[19] Computations are available from the authors on request.

[20] It can be seen that the main results of the model hold for values of parameter α other than 0.2.

π^{NY} if and only if $b > 0.7832$, and $\pi^{YY} > \pi^{NN}$ if and only if $b > 0.3756$. Therefore, if $b < 0.7832$ neither firm engages in ECSR since it is a dominant strategy for both firms. If $b > 0.7832$ there are two equilibriums: In one of them both firms engage in ECSR and in the other neither does. The first equilibrium is Pareto superior to the second, so both firms engage in ECSR. The explanation for these results is as follows. If a firm engages in ECSR it pays abatement costs and produces less, which puts it at a disadvantage. Under Cournot competition, production decisions are strategic substitutes (i.e. if a firm reduces its output, its rival reacts by increasing it), so it is not in the interest of the firms to engage in ECSR. However, under price competition prices are strategic complements: If one firm raises its price (which means producing less), the other reacts by doing likewise. Thus, undertaking ECSR activities leads to higher prices, which causes the rival to follow suit, reducing market competition and increasing revenues. Thus, if the rival chooses not to engage in ECSR, the firm that adopts ECSR faces a strong disadvantage, since it produces less and abates more. Therefore, a firm does not engage in ECSR when its rival does not do so. If the rival chooses to undertake ECSR activities, it is beneficial to do likewise if the goods are close substitutes. This is because the reaction functions in prices are positively sloped and if one firm raises its price, so does the other. If the goods are close substitutes, market competition is strong and it pays to engage in ECSR because both firms reduce their production, which decreases market competition. This means that the equilibrium in which both firms engage in ECSR dominates that in which neither does if $b > 0.7832$. If the goods are weak substitutes, competition in the product market is low so it is not of interest to adopt ECSR. It is better not to undertake ECSR activities, since this leads to lower costs, which permits a firm to gain market share at the expense of its rival.

We find that when environmental damage is global ($s = 1$), $\pi^{NN} > \pi^{YN}$ and $\pi^{NY} > \pi^{YY}$ for all b. Therefore, in equilibrium, neither firm engages in ECSR so the same result is obtained as under quantity competition. The reason for this is the following: The damage is global, so the environmental damage suffered by each country, which appears in expression (2), is greater than with local damage. Undertaking ECSR activities leads firms to raise prices, which causes their rival to do likewise, reducing market competition and increasing revenues. Since the damage is global, it weighs heavily on expression (2), i.e. the objective function of the firm that engage in ECSR. Therefore, a firm that adopts ECSR raises its price significantly. Its rival prefers not to engage in ECSR and to take advantage (it raises its price, but only slightly). As a result, in equilibrium the firms do not engage in ECSR.

We now consider now that governments implement environmental taxes. Under local damage, we find for both cooperative and non-cooperative taxes that $\pi^{YN} > \pi^{NN}$ and $\pi^{YY} > \pi^{NY}$ for all b. Therefore, the two firms engage in ECSR, so the same result emerges as under quantity competition. This is because, under price competition, when firms adopt ECSR they produce and abate less than when they do not engage in ECSR,[21] which leads the government to set lower taxes.

When the damage is global ($s = 1$), the results obtained under Cournot and price competition differ. With global damage and non-cooperative taxes, we find the following: If $b < 0.8221$, when only one firm engages in ECSR there is a corner solution and the firm that adopts ECSR does not emit pollution (so $q_i = a_i$ for this firm); if $b > 0.8221$ there is an interior solution. We find that $\pi^{NN} > \pi^{YNe}$ for $b < 0.8221$, and $\pi^{NYe} > \pi^{YY}$ if and only if $0.8221 > b > 0.6190$. If $b > 0.8221$ we find that $\pi^{NN} > \pi^{YN}$ and $\pi^{NY} > \pi^{YY}$. Finally, $\pi^{YY} > \pi^{NN}$ if and only if $b < 0.7368$. Therefore, if $b < 0.6190$ there are two equilibriums: in one both firms engage in ECSR and in the other neither does. The first equilibrium is Pareto superior to the second so both firms adopt ECSR. If $b > 0.6190$ there is only one equilibrium: Neither firm engages in ECSR. Therefore, the result differs from that obtained under quantity competition.

[21] This is because under price competition prices are strategic complements, so if one firms increases its price, thus reducing its output, the other does likewise.

Next, we consider global damage and cooperative taxes. In this case we find that $\pi^{NN} > \pi^{YN}$ if and only if $b > 0.8846$, and $\pi^{NY} > \pi^{YY}$ if and only if $b > 0.8812$. Therefore, if $b < 0.8812$ both firms engage in ECSR; if $0.8812 > b > 0.8846$ just one firm does so; and, finally, if $b > 0.8846$ neither firm adopts ECSR. This result coincides with that obtained under quantity competition only when the degree to which goods are substitutes is low ($b < 0.8812$). Otherwise the result differs.

When the environmental damage is local ($s = 0$) it has little weight in expression (2), so we find that in equilibrium both firms engage in ECSR. However, when the damage is global it has more weight in expression (2), which leads to lower production and market competition. Therefore, the equilibrium where both firms engage in ECSR only holds when the goods are weak substitutes (b sufficiently small), since in that case market competition is not sufficiently large. When goods are close substitutes, market competition is sufficiently large and firms do not undertake ECSR activities in equilibrium. Finally, in the cooperative case, for intermediate values of parameter b an asymmetric equilibrium arises in which only one firm engages in ECSR, because cooperative taxes are higher than non-cooperative taxes. This leads firms to produce less and abate more emissions, so it only pays for one firm to adopt ECSR for intermediate values of parameter b.

8. Conclusions

This paper analyzes the decision of firms as to whether or not to be environmentally responsible when they compete in an international market. We consider two firms located in different countries whose production damages the environment and may lead to transboundary pollution. Governments use emission taxes as their environmental policy instrument, either non-cooperatively or cooperatively. In addition, firms have to decide whether to adopt environmental corporate social responsibility or not. Therefore, the behavior of a firm may be due to two factors. First, an environmentally friendly firm has more incentive to reduce emissions than a profit-maximizing firm, since only the former cares about the environment. Second, an environmentally concerned firm reduces emissions voluntarily, so it pays less tax per unit of emission than a profit-maximizing firm, which leads the former to reduce emissions by less.

We find that when governments do not set environmental taxes, firms neither engage in ECSR nor reduce pollutant emissions. However, when governments implement environmental taxes non-cooperatively, firms engage in ECSR both under local damage and for sufficiently high values of environmental concern of firms under global damage. Therefore, under international trade the implementation of environmental policies by governments may encourage firms to adopt ECSR. When governments decide to cooperate in the implementation of environmental taxes, firms adopt ECSR on a voluntary basis under both local and global damage. This means that under global damage government cooperation in the implementation of environmental policies can increase the commitment of firms to the environment.

We also find that under local damage and non-cooperative environmental policies the decision of firms to be environmentally responsible leads to higher producer and consumer surpluses and less environmental damage, which means higher social welfare. However, under global damage, firms' profits are higher if they are environmentally friendly, the consumer surplus is only higher if firms' concern about ECSR is low enough, and environmentalists would prefer firms not to adopt ECSR.

Finally, we analyze whether the results obtained in the paper are robust. We show that the main results hold when the decision as to whether to adopt ECSR is taken by firms taking into account their objective functions, and when costs present decreasing returns to scale. We also find that the results of the paper may change if price competition is considered.

Credit author statement

Joint work by Juan Carlos Bárcena-Ruiz and Amagoia Sagasta.

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Appendix A. Non-cooperative environmental policy and local damage

When governments set up optimal environmental taxes non-cooperatively and only one firm adopts ECSR, the equilibrium values of output and profits are:

$$q^{YN} = \frac{3(A-c)(3+8\alpha)(2961+21636\alpha+34048\alpha^2)}{G},$$

$$q^{NY} = \frac{3(A-c)(8883+83808\alpha+241344\alpha^2+220672\alpha^3)}{G},$$

$$\pi^{YN} = \frac{(A-c)^2(3+8\alpha)(314020395+5448045420\alpha+36900207828\alpha^2+123667982064\alpha^3+213679317888\alpha^4+175333710848\alpha^5+49132347392\alpha^6)}{G^2},$$

$$\pi^{NY} = \frac{(A-c)^2(942061185+17787704976\alpha+135163093284\alpha^2+530112663072\alpha^3+1137097078848\alpha^4+1270746322944\alpha^5+580364025856\alpha^6)}{G^2},$$

$$V^{YN} = ((A-c)^2(942061185+18595420938\alpha+149207210244\alpha^2+626296252392\alpha^3+ 1468126729728\alpha^4+1874639533056\alpha^5+1132853051392\alpha^6+196529389568\alpha^7))/G^2,$$

where $G = 110403 + 1056744\alpha + 3101712\alpha^2 + 2895104\alpha^3$.

Appendix B. Non-cooperative environmental policy and global damage

When both firms adopt ECSR, in the fourth stage each firm chooses q_i that maximizes V_i given by (2). Solving this problem, we find the following:

$$q_i = \frac{(A-c) - 2(1+2\alpha)t_i + (1+4\alpha)t_j + 4\alpha(a_i+a_j)}{3+8\alpha}.$$

In the third stage, firm i chooses a_i that maximizes V_i given by (2). Solving, we obtain:

$$a_i = \frac{4\alpha(A-c)(15+64\alpha(1+\alpha)) + (27+258\alpha+856\alpha^2+896\alpha^3)t_i - 2\alpha(51+268\alpha+320\alpha^2)t_j}{2(3+8\alpha)(9+84\alpha+128\alpha^2)}.$$

In the second stage, governments decide their optimal environmental taxes to maximize their social welfare, given by (3). Solving, we find the following:

$$t^{YY} = \frac{4(A-c)(243+1602\alpha-114\alpha^2-20696\alpha^3-46912\alpha^4-28672\alpha^5)}{H_1}, i = 1,2,$$

where $H_1 = 3159 + 28926\alpha + 92496\alpha^2 + 112864\alpha^3 + 32512\alpha^4$; $t^{YY}$is positive only if $\alpha < 0.2657$. When $\alpha < 0.2657$ the following emerges:

$$q^{YY} = \frac{(A-c)(3+8\alpha)(243+1638\alpha+3144\alpha^2+320\alpha^3-1792\alpha^4)}{H_1},$$

$$\pi^{YY} = (A-c)^2(3+8\alpha)(255879+4161132\alpha+29405376\alpha^2+121834800\alpha^3+340167168\alpha^4+ +680280320\alpha^5+929957888\alpha^6+714137600\alpha^7+152305664\alpha^8 - 77070336\alpha^9)/(H_1)^2,$$

$$CS^{YY} = \left((A-c)^2(3+8\alpha)^2\left((243+1638\alpha+3144\alpha^2+320\alpha^3-1792\alpha^4\right)^2\right)\Big/\left(2(H_1)^2\right),$$

$$ED^{YY} = \left(8(A-c)^2(3+8\alpha)^2\left(81+840\alpha+2648\alpha^2+2464\alpha^3\right)^2\right)\Big/(H_1)^2,$$

$$V^{YY} = ((A-c)^2(3+8\alpha)(255879+4003668\alpha+25719552\alpha^2+85895856\alpha^3+151206912\alpha^4+102386432\alpha^5-96917504\alpha^6-266731520\alpha^7-236257280\alpha^8-77070336\alpha^9))/(H_1)^2,$$

$$W^{YY} = 2(A-c)^2\left(531441+8424324\alpha+49267278\alpha^2+96855912\alpha^3-250267968\alpha^4-1773601920\alpha^5-4028419584\alpha^6-4449816576\alpha^7-2327740416\alpha^8-596377600\alpha^9-205520896\alpha^{10}\right)\Big/(H_1)^2.$$

When $\alpha > 0.2657$, there is a corner solution (denoted by superscript e) and government i sets the tax $t^{YY} = 0$. In that case, the following is obtained:

$$a^{YYe} = \frac{2(A-c)\alpha(5+8\alpha)}{9+84\alpha+128\alpha^2}, q^{YYe} = \frac{(A-c)(3+20\alpha+16\alpha^2)}{9+84\alpha+128\alpha^2}$$

$$\pi^{YYe} = \frac{(A-c)^2(9+192\alpha+1116\alpha^2+2304\alpha^3+1280\alpha^4)}{(9+84\alpha+128\alpha^2)^2}, CS^{YYe} = \frac{(A-c)^2(3+20\alpha+16\alpha^2)^2}{(9+84\alpha+128\alpha^2)^2}$$

$$ED^{YYe} = \frac{8(A-c)^2(3+10\alpha)^2}{(9+84\alpha+128\alpha^2)^2}, V^{YYe} = \frac{(A-c)^2(9+120\alpha+636\alpha^2+1504\alpha^3+1280\alpha^4)}{(9+84\alpha+128\alpha^2)^2}$$

$$W^{YYe} = \frac{2(A-c)^2(-27-84\alpha+406\alpha^2+1472\alpha^3+768\alpha^4)}{(9+84\alpha+128\alpha^2)^2}$$

When neither firm engages in ECSR, both firms maximize profits so $\alpha = 0$. The equilibrium results for the case in which neither firm adopts ECSR are obtained by substituting $\alpha = 0$ in the results obtained when both firms adopt ECSR and there is no corner solution.

Now assume that firm i adopts ECSR while firm j maximizes profits. In the fourth stage, firm i chooses q_i to maximize V_i given by (2) whereas firm j chooses q_j to maximize π_j given by (1). Solving these problems, the following emerges:

$$q_i = \frac{(A-c)(1+4\alpha)+(1+4\alpha)t_j-2t_i+8\alpha(a_i+a_j)}{3+4\alpha}, q_j = \frac{(A-c)(1+4\alpha)-2(1+2\alpha)t_j+t_i-4\alpha(a_i+a_j)}{3+4\alpha}.$$

In the third stage, firm i chooses a_i to maximize V_i whereas firm j chooses a_j to maximize π_j. Solving, the following emerges:

$$a_i = \frac{4\alpha(A-c)(21+76\alpha+64\alpha^2)-(39+172\alpha+192\alpha^2)t_j+(27+48\alpha-32\alpha^2)t_i}{2(3+4\alpha)(9+42\alpha+32\alpha^2)},$$

$$a_j = \frac{-8\alpha(A-c)(3+22\alpha+24\alpha^2)+(27+210\alpha+568\alpha^2+512\alpha^3)t_j-8\alpha(3+4\alpha+8\alpha^2)t_i}{2(3+4\alpha)(9+42\alpha+32\alpha^2)}.$$

In the second stage, governments simultaneously choose the optimal taxes that maximizes their own social welfare given by (3). If $\alpha < 0.1082$, the following is obtained:

$$q^{NY} = \frac{(A-c)(3+4\alpha)(32805+383940\alpha+1530576\alpha^2+2676672\alpha^3+1958976\alpha^4+531840\alpha^5+795648\alpha^6+993280\alpha^7+163840\alpha^8)}{(H_2)},$$

$$q^{YN} = \frac{(A-c)(3+4\alpha)(32805+208980\alpha+605880\alpha^2+1748736\alpha^3+4771008\alpha^4+7681920\alpha^5+6452224\alpha^6+3491840\alpha^7+1736704\alpha^8)}{(H_2)},$$

$$t^{YN} = \frac{4(A-c)(32805+326835\alpha+1040364\alpha^2-27108\alpha^3-8539632\alpha^4-24701856\alpha^5-35320448\alpha^6-30024192\alpha^7-16214016\alpha^8-4849664\alpha^9)}{(H_2)},$$

$$t^{NY}=\frac{4(A-c)(32805+261225\alpha+971352\alpha^2+2453760\alpha^3+4419072\alpha^4+4853568\alpha^5+2662912\alpha^6+918528\alpha^7+778240\alpha^8+229376\alpha^9)}{(H_2)},$$

$$\begin{aligned}\pi^{NY}=\ &(A-c)^2(3+4\alpha)(4663394775+100814357700\alpha+986554868940\alpha^2+5611285802160\alpha^3+\\&20259171973440\alpha^4+48257582906880\alpha^5+77473502175744\alpha^6+87473819510784\alpha^7+\\&80781382397952\alpha^8+77531385397248\alpha^9+71333630017536\alpha^{10}+46462394957824\alpha^{11}+\\&21979884158976\alpha^{12}+13908366589952\alpha^{13}+8856549720064\alpha^{14}+2681334661120\alpha^{15}+\\&478620418048\alpha^{16}+52613349376\alpha^{17})/(H_2)^2,\end{aligned}$$

$$\begin{aligned}\pi^{YN}=\ &(A-c)^2(3+4\alpha)(4663394775+80725887900\alpha+649823222520\alpha^2+3173250219840\alpha^3+\\&10168370034768\alpha^4+21943311692544\alpha^5+35439008150016\alpha^6+68132612533248\alpha^7+\\&195325979489280\alpha^8+490356261421056\alpha^9+846536558297088\alpha^{10}+971619650240512\alpha^{11}+\\&707053853343744\alpha^{12}+242177212940288\alpha^{13}-95959631527936\alpha^{14}-166740965195776\alpha^{15}-\\&84968277540864\alpha^{16}-16605417308160\alpha^{17})/\ (H_2)^2,\end{aligned}$$

$$\begin{aligned}V^{YN}=\ &((A-c)^2(3+4\alpha)(4663394775+77856106500\alpha+583711962120\alpha^2+2476496426760\alpha^3+\\&5695017249168\alpha^4+2267963673120\alpha^5-27852580840320\alpha^6-87271408986624\alpha^7-\\&104760555807744\alpha^8+25609483339776\alpha^9+263951594102784\alpha^{10}+381335857856512\alpha^{11}+\\&229417966108672\alpha^{12}-58392141365248\alpha^{13}-235125382053888\alpha^{14}-208812384452608\alpha^{15}-\\&91114912612352\alpha^{16}-16605417308160\alpha^{17}))/\ (H_2)^2,\end{aligned}$$

where $H_2=426465+4369140\alpha+18793944\alpha^2+45789408\alpha^3+72151488\alpha^4+80406912\alpha^5+69764608\alpha^6+52283392\alpha^7+31219712\alpha^8+9175040\alpha^9$.

If $\alpha>0.1082$, the total emissions of the firm that engages in ECSR are negative, so there is a corner solution in which $a_i=q_i$. As this firm does not pay taxes, it does not matter what tax its government sets. Solving this case, the following emerges:

$$t^{NYe}=\frac{81(A-c)}{269},\pi^{YNe}=\frac{5000(A-c)^2}{72361},\pi^{NYe}=\frac{25605(A-c)^2}{289444},V^{YNe}=\frac{(A-c)^2(10000-3249\alpha)}{144722}.$$

Appendix C. Cooperative environmental policy and local damage

When both firms engage in ECSR and governments set up taxes cooperatively, the equilibrium values (denoted by a circumflex accent mark) are:

$$\widehat{t}^{YY}=2(A-c)(1+2\alpha)\left(81+492\alpha+560\alpha^2-1024\alpha^3-1536\alpha^4\right)/I_1,$$

$$\widehat{q}^{YY}=3(A-c)(1+4\alpha)(3+4\alpha)\left(15+76\alpha+80\alpha^2\right)/I_1,$$

$$\widehat{\pi}^{YY}=\frac{2(A-c)^2(1+4\alpha)(3+4\alpha)(4131+63666\alpha+402576\alpha^2+1346144\alpha^3+2551552\alpha^4++2710016\alpha^5+1462272\alpha^6+294912\alpha^7)}{(I_1)^2},$$

$$\widehat{CS}^{YY}=9(A-c)^2(1+4\alpha)^2(3+4\alpha)^2\left(15+76\alpha+80\alpha^2\right)^2/(I_1)^2,$$

$$\widehat{ED}^{YY}=8(A-c)^2(1+4\alpha)^2(3+4\alpha)^2\left(9+44\alpha+48\alpha^2\right)^2/(I_1)^2,$$

$$\widehat{V}^{YY}=\left(2(A-c)^2\left(12393+254178\alpha+2232864\alpha^2+10979328\alpha^3+33125888\alpha^4+63140864\alpha^5+75194368\alpha^6+52879360\alpha^7+19070976\alpha^8+2359296\alpha^9\right)\right)/(I_1)^2,$$

$$\widehat{W}^{YY}=3(A-c)^2(1+4\alpha)(3+4\alpha)\left(9+44\alpha+48\alpha^2\right)/I_1,$$

where $I_1=567+5736\alpha+20560\alpha^2+30592\alpha^3+16128\alpha^4$.

When neither firm engages in ECSR equilibrium results are obtained by substituting $\alpha=0$ in the above expressions. When only one firm adopts ECSR, the equilibrium values are:

$\widehat{t}^{YN} = 2(A-c)(1+2\alpha)\left(1539+1020\alpha-5728\alpha^2\right)/I_2$, $\widehat{t}^{NY} = 2(A-c)\left(1539+6816\alpha+7568\alpha^2\right)/I_2$,

$\widehat{q}^{YN} = 3(A-c)(3+8\alpha)(285+656\alpha)/I_2, \widehat{q}^{NY} = 3(A-c)\left(855+3804\alpha+4256\alpha^2\right)/I_2$,

$\widehat{\pi}^{YN} = 2(A-c)^2(3+8\alpha)\left(1491291+10776078\alpha+27409920\alpha^2+27746080\alpha^3+8202496\alpha^4\right)/(I_2)^2$,

$\widehat{\pi}^{NY} = 2(A-c)^2\left(4473873+39761604\alpha+132742872\alpha^2+197291904\alpha^3+110148224\alpha^4\right)/(I_2)^2$,

$\widehat{V}^{NY} = 2(A-c)^2\left(4473873+43205886\alpha+158416416\alpha^2+266910288\alpha^3+190625024\alpha^4+32809984\alpha^5\right)/(I_2)^2$,

where $I_2 = 10773 + 49200\alpha + 56416\alpha^2$.

Appendix D. Cooperative environmental policy and global damage

When both firms engage in ECSR, the equilibrium values are:

$\widehat{t}^{YY} = 2(A-c)\left(351+2010\alpha+2504\alpha^2-832\alpha^3+1024\alpha^4\right)/I_3$,

$\widehat{q}^{YY} = (A-c)\left(405+2268\alpha+3072\alpha^2-256\alpha^3+512\alpha^4\right)/I_3$,

$\widehat{\pi}^{YY} = 2(A-c)^2\left(143613+1711530\alpha+7708896\alpha^2+15755712\alpha^3+13291136\alpha^4+3157504\alpha^5+2177024\alpha^6+425984\alpha^7+131072\alpha^8\right)/(I_3)^2$,

$\widehat{CS}^{YY} = (A-c)^2\left(405+2268\alpha+3072\alpha^2-256\alpha^3+512\alpha^4\right)^2/(I_3)^2$,

$\widehat{ED}^{YY} = 32(A-c)^2\left(27+156\alpha+200\alpha^2-96\alpha^3\right)^2/(I_3)^2$,

$\widehat{V}^{YY} = 2(A-c)^2\left(143613+1699866\alpha+7574112\alpha^2+15193536\alpha^3+12375680\alpha^4+2996736\alpha^5+2791424\alpha^6+278528\alpha^7+131072\alpha^8\right)/(I_3)^2$,

$\widehat{W}^{YY} = (A-c)^2\left(243+1404\alpha+2016\alpha^2+256\alpha^4\right)/I_3$,

where $I_3 = 1917 + 11256\alpha + 16720\alpha^2 + 768\alpha^3 + 2048\alpha^4$.

When neither firm adopts ECSR, the equilibrium values are obtained by substituting $\alpha = 0$ in the above expressions. When one firm adopts ECSR, equilibrium values are:

$\widehat{t}^{YN} = 2(A-c)\left(1053+5202\alpha+4416\alpha^2-13440\alpha^3-24320\alpha^4-12800\alpha^5\right)/(3I_4)$,

$\widehat{t}^{NY} = 2(A-c)\left(1053+9252\alpha+25944\alpha^2+25536\alpha^3+6656\alpha^4+2048\alpha^5+6144\alpha^6\right)/(3I_4)$,

$\widehat{q}^{YN} = (A-c)\left(1215+11664\alpha+39024\alpha^2+53376\alpha^3+29440\alpha^4+10240\alpha^5+12288\alpha^6\right)/(3I_4)$,

$\widehat{q}^{NY} = (A-c)(3+4\alpha)\left(405+1080\alpha+192\alpha^2-640\alpha^3-256\alpha^4\right)/(3I_4)$,

$\widehat{\pi}^{YN} = 2(A-c)^2\left(1292517+20436786\alpha+145538208\alpha^2+602902224\alpha^3+1575861984\alpha^4+2677847040\alpha^5+3031922688\alpha^6+2454872064\alpha^7+1643036672\alpha^8+933363712\alpha^9+365428736\alpha^{10}+122683392\alpha^{11}+56623104\alpha^{12}\right)/(3I_4)^2$,

$\widehat{\pi}^{NY} = 2(A-c)^2\left(1292517+15647256\alpha+86565024\alpha^2+282319776\alpha^3+571581216\alpha^4+704014848\alpha^5+515960832\alpha^6+285155328\alpha^7+238075904\alpha^8+171311104\alpha^9+42991616\alpha^{10}+12582912\alpha^{11}+18874368\alpha^{12}\right)/(3I_4)^2$,

$\widehat{V}^{YN} = \left(2(A-c)^2\left(1292517+20331810\alpha+144091872\alpha^2+594125712\alpha^3+1544992992\alpha^4+2607998976\alpha^5+2925901824\alpha^6+2347671552\alpha^7+1575796736\alpha^8+912130048\alpha^9+365428736\alpha^{10}+122683392\alpha^{11}+56623104\alpha^{12}\right)\right)/(3I_4)^2$,

where $I_4 = 1917 + 13296\alpha + 33568\alpha^2 + 34048\alpha^3 + 12032\alpha^4 + 4096\alpha^5 + 8192\alpha^6$.

If $\alpha > 0.0450$, the total emissions of the firm that does not engage in ECSR are negative, so there is a corner solution where that firm abates all emissions. As the firm does not pay taxes, it does not matter what tax its government sets. Considering this, the following emerges:

$\widehat{t}^{YNe} = \dfrac{2(A-c)(1+2\alpha)(8281+11844\alpha-12352\alpha^2)}{47579+202496\alpha+215552\alpha^2}, \widehat{\pi}^{NYe} = \dfrac{2(A-c)^2(9163+38556\alpha+40576\alpha^2)^2}{(47579+202496\alpha+215552\alpha^2)^2}$,

$\widehat{\pi}^{YNe} = \dfrac{2(A-c)^2(7+16\alpha)(13426735+86528022\alpha+190019872\alpha^2+150877024\alpha^3+19071488\alpha^4)}{(47579+202496\alpha+215552\alpha^2)^2}$,

$$\widehat{V}^{YNe} = \frac{2(A-c)^2(93987145 + 813522598\alpha + 2653983472\alpha^2 + 3899942032\alpha^3 + 2264622592\alpha^4 + 152571904\alpha^5)}{(47579 + 202496\alpha + 215552\alpha^2)^2}$$

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