Pollution and environmentalists' participation in Emissions Trading Systems[1]

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Abstract

In this paper we show that the participation by an environmental group in a permit market does not necessarily result in more investment in abatement or even less pollution. There is a U-shaped relationship between the emission per unit of output and the extra weight given by the environmental group to the reduction of emissions. For high values of this weight, firms invest less in abatement but also produce less. For lower values, firms invest more in abatement but also produce more, which may result in higher emissions levels.

Keywords: Emissions Trading Systems; Abatement; Induced Technological Change; Environmental Group

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1 Introduction

Emissions trading systems (ETSs henceforth) are market based instruments used to control pollution. The idea of the ETSs or permits markets has its origins in Coase (1960) and Dales (1967) and relies upon the creation of economic incentives to reduce pollution through the exchange of permits. Following the Kyoto Protocol (1998) ETSs have become major tools in the anti-pollution policy in a number of countries.[1]

Several legal frameworks opened up the participation in the ETSs to third parties, such as citizens, consumers, environmental organizations, etc. This right to participate is contemplated, for example, in the United Nations' Framework Convention for Climate Change (Guidelines FCCP/ CP/ 2001/ 2/ Add.4) and in the EU's Directive 2003/87/EC. Similarly, in the US, third parties can participate in the Sulphur Allowance Trading Program (SAT) and in the Clean Air Incentives Scheme (RECLAIM). Groups such as the Acid Retirement Fund and the Clean Air Conservancy Trust in the US or Sandbag in the UK are examples of NGOs who use their funds (mainly collected through charitable donations) to purchase permits from ETSs. By withdrawing permits from the market, this type of organizations aim at increasing the price of polluting and therefore at inducing firms to invest in abatement technologies to reduce their emissions.[2]

From the theoretical point of view, a number of contributions have provided some reasons why the participation by third parties should be allowed (see, for example, Shrestha, 1998; Smith and Yates, 2003a, 2003b; English and Yates, 2007; Rousse 2008). Generally, it is argued that third parties may have better information regarding the damage value than the regulator. Thus, allowing them to participate in the ETS may be used by the regulator to learn about society's preferences. In addition, even if the regulator had enough information regarding optimal emissions, he/she could issue a socially excessive number of permits due to lobbying or political pressure (Eshel and Sexton, 2009). This would leave some scope for the participation of third parties in ETSs. It has been shown that third parties may actually prefer to participate in the permits' market instead of lobbying the regulator to reduce

[1] For example, in the US, there are ETSs in place for the reduction of SOx and NOx emissions. Also, the European Union (EU) has implemented an ETS for the reduction of CO_2. This is the largest application of ETS in geographic terms (Newbery, 2008).

[2] For example, this objective is very clearly stated in the Acid Rain Retirement Fund's ethos.

the total number of allocated permits (Malueg and Yates, 2006). Moreover, Perino (2013) highlights that since any emissions in a cap and trade scheme are fully offset, one of the few options at the citizens' disposal to reduce total emissions is to buy permits.[3] On the negative side, the participation by citizens can be afflicted by free-riding problems (Smith and Yates, 2003b). All in all, the participation by third parties in ETSs is not simply a theoretical scenario. In fact, there is empirical evidence on the presence of third parties in ETSs (see Schwarze and Zapfel, 2000; Israel, 2007; and Joskow *et al.* 1998).

There is a literature strand exploring the linkages between the existence of policies against climate change and the degree of technological change. For example, Newell *et al.* (1999) and Popp (2002) analyze how higher energy prices induce more technological innovation.[4] Some other contributions have compared the propensity to technological innovation generated by several market-based instruments (Fischer *et al.*, 2003; Requate and Unold, 2003; and Kerr and Newell, 2003), reaching mixed conclusions.[5] Finally, some recent contributions have warned that a stricter environmental policy does not necessarily increase the incentives for green innovation (Perino and Requate, 2012; Brechet and Meunier, 2012). The interaction between emission taxation and the existence of environmentally conscious consumers has been considered by Gil-Molto and Varvarigos (2013), who find that the range of values for which the emission tax increases the incentives to adopt a clean technology is narrower when the consumers' environmental awareness is stronger.[6] All in all, despite the relevance of the issue, the literature has

[3]Using the example in Perino (2013), taking the bus in Europe is worse for the environment than flying, as air travelling is covered by an ETS (therefore the marginal emissions are perfectly offset) while travelling by bus is not. Perino (2013) lists other two options at citizens' disposal: i) To reduce emissions not captured by the ETS and; ii) To vote or lobby the regulator to reduce the cap.

[4]See also Chakravorty et al. (1997). On the other hand, Goulder and Schneider (1999) and Goulder and Mathai (2000) examine the implications of Induced Technological Change (ITC) for CO_2 abatement policy.

[5]Recently, the use of informational campaigns to raise environmental awareness as a policy instrument has become the focus of several studies (see Petrakis et al. 2005; Garcia-Gallego and Georgantzis 2009, 2011). However, these studies focus on the issue of product innovation, rather than on emissions abatement.

[6]In their setting, the existence of environmentally conscious consumers only affects firms through their demands: As pollution goes up, consumers shift resources away from consumption to environmental activities, thereby affecting firms' incentives to invest in environmental R&D.

largely overlooked the implications of third parties' participation in ETSs which affects the price of permits, for firms' investments in abatement or green technologies.

The objective of our paper is therefore to study the interaction between firms and an environmental group in an ETS focusing on the implications for firms' decisions to invest in abatement technologies. We introduce an oligopsony purchasing permits in an ETS. The assumption of oligopsony is made to reflect the characteristics of many permit markets where players have market power. This assumption seems particularly pertinent in the context of small regional permit markets. Some examples are the permit markets for emissions of Nitrogen Oxide and Sulfur Oxide emissions in Ontario or for CO2 emissions in Denmark (see Muller *et al.*, 2002; and Schwartz, 2007). However, even large permit markets could be affected by less than perfect competition. For example, Wirl (2009) points out that the ETS is populated by large players, mostly from the energy generation sector, who can be argued to have market power.

In our paper, we allow an environmental group to purchase permits from the market. Therefore, the participation of the environmental group affects the price of the permits and, as a consequence, firms' incentives to invest in abatement technologies. An important consequence of assuming an environmental group (rather than individual citizens) is that its members can perfectly coordinate as in Shresta (1989), which rules out any free-riding problems.

In our model, the environmental group may choose to participate to push the price of permits up: A priori, withdrawing permits would encourage investment in abatement, as it would make polluting more expensive. This provides the rationale behind the environmentalists' motivations. We will study how the emission levels and firms' abatement choices are affected by the presence of an environmental group in the ETS. We will also compare the equilibrium outcomes with and without its participation.

We assume that the environmental group decides on how many permits to purchase without consumption concerns. That is, the environmental group acts in the ETS in the role of citizen (or Homo Politicus) and not consumer (or Homo Economicus). When economic agents act as consumers, they are concerned about their own wellbeing while when they act as citizens, they act in the interest of the public (or the environment, in our paper).There is an important body of theoretical and empirical literature which makes a distinction between agents acting as consumers or as citizens (Sagoff, 1988;

Blamey et al. 1995; Vatn and Bromley, 1994; Nyborg, 2000), pointing out that individuals may act as either citizens or consumers in different situations.

Our results show that the participation by an environmental group in the ETS does not necessarily induce firms to invest more in abatement or even to lower emissions levels. The participation of the environmental group in the permit market has two effects: It induces firms to invest more in the abatement technology but it also leads them to reduce output. In turn, this latter effect reduces firms' incentives to invest in the abatement technology. A U-shaped relationship exists between the resulting emissions per unit of output and the weight given to the withdrawal of permits by the environmental group. If this weight is high enough, firms will invest less in abatement in the presence of the environmentalists, resulting in higher emissions per unit of output but also lower output. For relatively lower values of this weight, firms will invest more in abatement but will produce more, which may result in more pollution.

The rest of the paper is structured as follows: Section 2 introduces our model. The cases without and with the environmentalists' participation in the ETS are analysed respectively in sections 3 and 4. A comparative analysis on output and emissions levels across the two cases can be found in section 5. Section 6 presents some robustness checks. Section 7 provides some discussion of the implications of our analysis and concludes.

2 The model

In our model, two polluting firms compete for pollution permits as an oligopsony but are each monopolists in their own output markets. The inclusion of two firms (rather than only one) in our model is due to several reasons. As discussed in the introduction, the case of oligopsony is empirically relevant because in many permit markets participating firms constitute oligopsonies.[7] For simplicity, we focus on the case with two firms, which allows us to reflect the essential features of competition in an oligopsony. In particular, we can show that firms are strategically dependent on each other's output choices even when they do not compete in the output markets.

[7] As mentioned before, this assumption seems particularly fitting for the modelling of small regional permit markets. However, it can be argued that even in large ETSs such as the EU ETS, players may have some degree of market power. See discussion of this assumption in the Introduction.

Each firm faces a linear inverse demand function such as[8]

$$P_i = a - q_i \tag{1}$$

where q_i is the level of output produced by firm i.

Prior to starting production, firms invest in an integrated abatement technology to reduce their emissions per unit of output. We denote the emissions per unit of output ratio by k. Therefore, a lower k implies cleaner production. We assume that reducing the emission per unit of output entails the following cost

$$F_i = \gamma(1 - k_i)^2. \tag{2}$$

F_i is assumed to be quadratic to reflect the existence of diminishing returns to investment in the abatement technology. For the sake of simplicity, we assume that $k_i \in (0, 1)$.

Total emissions by firm i are

$$y_i = k_i q_i. \tag{3}$$

We define the total level of pollution or environmental damage as the aggregation of individual emissions levels.[9]

$$E = y_1 + y_2 \tag{4}$$

Each firm must buy permits to offset its own emissions on a 1 to 1 ratio (that is, one permit per unit of emissions). Consequently, each firm's demand for permits is given by y_i. The government is the sole supplier of permits in the ETS. Furthermore, there is no grandfathering of permits. We contemplate two cases: In the first case, only firms are allowed to take part in the ETS. In the second case, an environmental group can also take part in the ETS. As in Eshel and Sexton (2009), we consider the case where the environmental group deems the environmental policy too lenient. This would

[8]We do not contemplate the case where there is competition in the final market so that to be able to isolate the effect of competition in the permits market. We check the robustness of our results to the relaxion of this and other assumptions of our model in section 6.

[9]Assuming that the environmental damage is a quadratic function of output does not change our results qualitatively. We discuss this in section 6.

imply that they consider permit prices to be too low.[10] In such a situation, the environmental group may choose to participate in the ETS to increase the price of permits available to firms and, at least a priori, encourage them to invest in the abatement technology. We denote the environmental group's demand for permits by x. As mentioned above, the two firms (and the environmental group when they participate) constitute an oligopsony in the permits market. Thus, the demand for permits is:

$$D_p = y_1 + y_2 + x \tag{5}$$

where $x = 0$ when the environmental group does not participate in the permits market.

As we wish to focus on the effect of the presence of the environmental group on firm's technological choices, we abstain from explicitly modelling the supply and the institutional characteristics of the market. Instead, we consider a reduced-form solution for the market; that is, that the equilibrium price of permits is increasing in the demand for permits, $R^e = f(D_p) = f(y_1 + y_2 + x)$, where $f' > 0$. This would hold in a variety of scenarios. For example, it would hold when the government sets a maximum cap on emissions and allocates permits to cover this cap (fixed supply) through a uniform price auction. Alternatively, we may think of a government that has two distinct objectives: raising revenues and reducing emissions to improve welfare (as in Antelo and Bru, 2009). In such a case, the government would be willing to supply extra permits as long as they could charge a (sufficiently) higher price for them. This would lead to a supply function which is increasing in the price.[11] In both these scenarios (fixed supply and supply increasing in the price), the equilibrium price would be increasing in the demand for permits by the two firms and the environmental group. For the sake of simplicity, we assume that the equilibrium price of permits R^e is linearly increasing in the demand of permits, i.e. $f(y_1 + y_2 + x) = \delta \times (y_1 + y_2 + x)$. Therefore

$$R^e = \delta(y_1 + y_2 + x). \tag{6}$$

[10] In fact, there is evidence from the pilot phase of the EU ETS showing that the level of total permits was set so high that it did not even effectively constrain firms (Anderson and Di Maria, 2011).

[11] Although their motivations may differ from the ones described here, it is worth noting that the government has explicitly chosen not to set a cap on total emissions in the New Zealand ETS.

In what follows, we normalize δ to 1.[12,13]

We assume that firms do not incur any other production costs than those derived from the acquisition of permits, that is

$$C_i(y_i) = R^e y_i. \tag{7}$$

All in all, firms' profits can be written as follows

$$\pi_i = P_i q_i - R^e y_i - \gamma(1 - k_i)^2. \tag{8}$$

We assume that the environmentalists act as citizens in the ETS. The environmental group chooses x to maximize the following objective function:[14]

$$\Omega = -E + zx + m \tag{9}$$

subject to their budget constraint

$$m + R^e x = I \tag{10}$$

where E is the environmental damage, as defined before, m is the numeraire and z is the extra weight that the environmentalists give to the reduction of emissions according to their environmental preferences. One can interpret z as the degree of impure altruism which characterizes the environmental group.[15] We impose $z < 2a$, to guarantee positive output. That is, we rule out the possibility that the weight they give to the reduction of emissions, z, is so high that they induce firms to stop producing altogether. In the main body of the paper we assume that the group does not have any other

[12] Assuming that $\delta = 1$ does not affect qualitatively our results. This parameter only introduces a scale factor in the marginal cost of firms.

[13] Let us consider a supply function $\varpi + \frac{R}{\delta}$, a case which captures the scenario where the supply of permits is increasing in the price. It is straightforward to establish that the result in (5) can be derived from the equilibrium in the market for permits, once we normalise $\varpi = 0$. Again, such normalisation would only remove scale effects from the subsequent analysis, without bearing on the qualitative results.

[14] In section 6, we will also conduct some checks on the robustness of our results to changes in the objective function of the environmental group.

[15] Following this interpretation, the environmental group does not only care about externalities, but they also obtain some utility from withdrawing permits *per se*, because of the associated "warm glow", in the spirit of Andreoni (1989, 1990). There is ample experimental evidence of impure altruism in contributions to public goods (Palfrey and Prisbey, 1996, 1997; and Goeree, Holt and Laury, 2002). For further details on Environmentals NGOs' motivations see Asproudis (2011).

consumption concerns (that is, they act as citizens and not consumers in the ETS).[16] We also impose that γ is sufficiently high for an interior solution to arise in the technology choice stage.[17]

We will analyze and compare two cases: When the environmentalists' participation in the ETS is not allowed and when it is indeed allowed. The timing of the game is as follows: As firms' choices of k imply a long term commitment, we assume that they take place in the first stage. In the second stage, the two firms and the environmental group, if allowed to participate, buy permits. In the case of the firms, their demand for permits will be determined by their choice of output, given that at this stage their emissions per unit of output have been already fixed. We assume that all players move simultaneously in each stage. In both cases, we solve the game by backwards induction to analyze the Subgame Perfect Nash Equilibrium (SPNE). We use subscripts $_G$ and $_{NG}$ to denote the solutions to the scenarios without and with the environmental group's participation in the ETS. All proofs to our lemmata and propositions are relegated to the appendix.

3 The environmental group is not allowed to participate in the ETS market

In this section, we solve the game where the environmental group is excluded from the ETS market. Therefore, x is set to zero ($x = 0$). In the last stage, firms choose their output levels in order to maximize their profits. The first order condition (FOC henceforth) yields:

$$\frac{\partial \pi_i}{\partial q_i} = a - 2q_i - k_i^2 q_i - k_i(k_i q_i + k_j q_j) = 0. \tag{11}$$

Solving for q_i, we obtain firm i's reaction function,

$$q_{i,NG}^R = \frac{a - k_i k_j q_j}{2(1 + k_i)^2}. \tag{12}$$

[16] However, one of the checks we present in section 6 is whether our results are robust to introducing consumer surplus in the objective function of the environmental group. We can anticipate that our results are qualitatively the same.

[17] In particular, we require that $\gamma > 0.34a^2$ to guarantee that the SOCs for maximization in the investment stage are fulfilled both with and without the environmental group's participation in the ETS.

From the reaction functions we can see that although firms do not compete in the final product market, their output levels are negatively related ($\partial q_i^R/\partial q_j = -k_i k_j < 0$ for any $k_i, k_j \in (0,1)$). This implies that firms' decisions on output are strategic substitutes. Furthermore, the more polluting production is (that is, the higher k_i and k_j are), the stronger that relationship is. In fact, firms' output levels are not independent from each other because the price of permits (which affects firms' marginal cost of production) depends on both firms' demand for permits, which, in turn depend on their respective output levels and investments in abatement.

Solving the system of reaction functions, we obtain the equilibrium level of output[18]

$$q_{i,NG}^* = \frac{a(2 - k_i k_j + 2k_j^2)}{4(1+k_j^2) + k_i^2(4+3k_j^2)}. \tag{13}$$

It is easy to see that the derivative of $q_{i,NG}^*$ with respect to k_i

$$\frac{\partial q_{i,NG}^*}{\partial k_i} = \frac{-a(k_j(4(1+k_j^2) + k_i^2(4+3k_j^2)) + 2k_i(4+3k_j^2)((2-k_ik_j+2k_j^2)))}{(4(1+k_j^2)+k_i^2(4+3k_j^2))^2}, \tag{14}$$

is negative for any $k_i, k_j \in (0,1)$. This implies that the more polluting firm i's production is, the less it produces. The intuition for this is that as k_i increases, firm i requires more permits to produce the same level of output. In addition, the price of permits rises (due to more permits being demanded). Consequently, firm i's marginal cost of production increases, inducing firm i to decrease its output. Our next lemma summarizes our first result.

Lemma 1 *$q_{i,NG}^*$ is decreasing in k_i.*

Substituting $q_{i,NG}^*$ and $q_{j,NG}^*$ into firms' profit functions and rearranging yields

$$\pi_i(q_{i,NG}^*) = (1+k_i^2)(q_{i,NG}^*)^2 - \gamma(1-k_i)^2. \tag{15}$$

[18] The second order conditions (SOCs henceforth) for a maximum are fulfilled.

In the first stage, firms choose k_i to maximize their profits. The FOC yields

$$\frac{\partial \pi_i}{\partial k_i} = 2k_i(q^*_{i,NG})^2 + 2(q^*_{i,NG})\frac{\partial q^*_{i,NG}}{\partial k_i}(1+k_i^2) + 2\gamma(1-k_i) = 0. \tag{16}$$

We denote the equilibrium solution in symmetry k^*_{NG}. Using the implicit function theorem we can then characterize the relationship between k^*_{NG}, and the parameters a and γ. Our finding is the following:[19]

Proposition 1: k^*_{NG} *is increasing in* γ *and decreasing in* a.

In other words, the higher γ and the lower a, the higher the resulting emissions per unit of output. Both a and γ are related to the profitability of investing in the abatement technology. Essentially γ scales up the cost of cleaning up production. The parameter a is related to the market size. Higher market sizes (higher a) will lead to higher output levels (other things being equal). This, in turn, will lead to higher demand for permits and therefore higher permit prices. Given this, firms have a stronger incentive to reduce their emissions per unit of output in larger markets.

4 The environmental group is allowed to participate in the ETS market.

In this section, we solve the game where the environmental group can participate in the ETS. In the last stage, firms choose their output levels in order to maximize their profits (implicitly determining their demand for permits) and the environmental group chooses x to maximize its objective function subject to its budget constraint. The FOC for the firms yields:

$$\frac{\partial \pi_i}{\partial q_i} = a - 2q_i - xk_i - k_i^2 q_i - k_i(k_i q_i + k_j q_j + x) = 0. \tag{17}$$

In order to solve the environmental group's problem we substitute the budget constraint into the objective function of the environmental group to

[19] In the proof in the appendix we also show that there is one and only one solution for k in symmetry.

eliminate m as a choice variable. It follows that the FOC for maximization is:

$$\frac{\partial \Omega}{\partial x} = z - 2x - k_i q_i - k_j q_j = 0 \tag{18}$$

Solving the system of FOC for maximization for the firms in (17), we obtain firm i's reaction function:

$$q_{i,G}^R = \frac{a - k_i k_j q_j - k_i x}{2(1+k_i)^2}. \tag{19}$$

As in the case without the environmental group's participation in the ETS, firms' outputs are strategic substitutes, even in the absence of competition in the product market. As before, the more polluting each of the firms' production is (that is, the higher k_i and k_j are), the stronger the strategic substitutability between their outputs is. Furthermore, firm i's output and the number of permits withdrawn by the environmentalists are also strategic substitutes. This relationship is stronger the more polluting firm i's production is. Solving the system of reaction functions $q_{i,G}^R$ and $q_{j,G}^R$, we obtain the equilibrium level of output for each firm as a function of x:[20]

$$q_{i,G}^*(x) = \frac{a(2 - k_i k_j + 2k_j^2) - k_i(2 + k_j^2)x}{4(1+k_j^2) + k_i^2(4 + 3k_j^2)}. \tag{20}$$

After substituting (20) into (18) and solving for x, we obtain the equilibrium level of permits purchased by the environmental group:[21]

$$x_G^* = \begin{cases} \dfrac{z(4(1+\sum_{i=1}^{2} k_i^2)+3k_i^2k_j^2) - a(2+k_ik_j)\sum_{i=1}^{2} k_i}{2(4+3\sum_{i=1}^{2} k_i^2 + 2k_i^2k_j^2)} > 0 & if \;\; \frac{a}{z} > \dfrac{4(1+\sum_{i=1}^{2} k_i^2)+3k_i^2k_j^2)}{(2+k_ik_j)\sum_{i=1}^{2} k_i} \\ 0 & otherwise \end{cases} \tag{21}$$

In order to analyze the behavior of the environmental group, it is sufficient to analyze x_G^* in symmetry, as the two markets and firms are symmetric and they receive the same weight in the environmentalists' objective function (in other words, the environmentalists do not care more about the emissions by

[20]The SOCs for a maximum are fulfilled.

[21]We focus on the interior solution were $R^e x_G^* \leq I$. The SOC for a maximum is met.

one firm or the other). $x_G^*(k_i,k_j)$ evaluated in symmetry ($k_i = k_j = k$) is

$$x_G^*|_{k_i=k_j=k} = \begin{cases} \frac{z(2+3k^2)-2ak}{4(1+k^2)} > 0 & if \ \frac{a}{z} < \frac{2+3k^2}{2k} \\ 0 & otherwise \end{cases} \tag{22}$$

The following proposition characterizes x_G^*:

Proposition 2: *Consider x_G^* in symmetry. There is a critical value of z, $z_{cv} = \frac{2ak}{(2+3k^2)}$ below which the environmental group will not take part in the ETS. If $z > z_{cv}$, the environmental group will withdraw more permits the higher z is and the lower a is.*

First of all, notice that the environmentalists will only take part in the ETS if z is high enough. Thus, even if they are allowed to, they may choose not to participate in the permits market. If they participate, the equilibrium number of permits they withdraw will be decreasing in a. As discussed above, the higher a is (the larger the market), the more profitable it is to invest in the abatement technology. Therefore, the higher a is, the less necessary it is to induce firms to invest in the abatement technology by making permits more expensive. Furthermore, the number of permits withdrawn by the environmental group is increasing in z. The higher the weight they give to the reduction of emissions in their objective function, the more permits they purchase in equilibrium.

Finally, after substituting (21) into (20), we can state the following:

Lemma 2 *$q_{i,G}^*$ is decreasing in k_i.*

In other words, as in the case without the environmental group, there is a negative relationship between how polluting production is and the level of output in equilibrium.

Now we proceed to solve the first stage where firms choose k_i. Substituting (21) into (20) and the latter into the profit function and applying the FOC for maximization yields:

$$\frac{\partial \pi_{i,G}}{\partial k_i} = 2k_i(q_{i,G}^*)^2 + 2(q_{i,G}^*)\frac{\partial q_{i,G}^*}{\partial k_i}(1+k_i^2) + 2\gamma(1-k_i) = 0. \tag{23}$$

Unfortunately, the closed-form solution for the first order condition is again very intricate, therefore we resort to the implicit function theorem to characterize the symmetric equilibrium solution k_G^*. In the next proposition we characterize k_G^*:[22]

Proposition 3: *Consider the case where the environmental group is active in the ETS. Then,*

i. there is a critical value of z, z_h, above (below) which $k_G^*(z)$ is decreasing (increasing) in z. The critical value of z is increasing in a.

ii. there is a critical value of z, $z_l \geq z_h$ beyond which $k_G^* > k_{NG}^*$.

Proposition 3.i states that there is a U-shape relationship between the equilibrium emissions per unit of output and z when the environmentalists take part in the ETS. As z increases, firms will tend to invest more in the abatement technology (reduce k) up until a critical point of z, where increases in z will actually reduce the incentives to invest in the abatement technology . The intuition behind this result is the following: As z increases, the environmentalists tend to withdraw more permits from the market, making permits more expensive. This has two effects: First, firms tend to invest more in the abatement technology, as polluting is more expensive. Second, firms reduce their output levels (note that q_i^* is decreasing in x) because the higher permit price implies a higher marginal cost of production for firms. As firms reduce their production levels, the investment in the abatement technology becomes less profitable. The interaction between these two effects will determine the resulting emissions per unit of output. For low levels of z, the first effect dominates the second effect. However, for high levels of z, the second effect dominates instead. Proposition 3.i also states that z_h is increasing in a. In other words, larger market sizes make the second effect above (reduction of output) less likely to outweigh the first effect (reduction of emissions per unit of output).[23]

Perino and Requate (2012) and Brechet and Meunier (2012) show that the adoption incentives for a new cleaner technology are non-monotonic in the

[22] In the proof in the appendix we also show that there is one and only one solution for k in symmetry.

[23] Furthermore, it can be easily shown that γ plays the same role as in the case without the environmentalists participation, that is, k_G^* is increasing in γ.

stringency of environmental regulation. The underlying mechanisms behind the U-shape result in our paper are the same as in the above mentioned contributions, although their settings are quite different to ours. Both those papers assume a continuum of small firms and a discrete technology choice (new vs. old technology). Furthermore, they do not include the presence of any environmental groups. In those contributions, the non-monotonicities arise because the marginal abatement costs curves of the old and the new technology cross, due to the fact that the new technology is associated with a lower emission to output ratio and that emissions are proportional to output. As a result, a more stringent policy on emissions (which increases the cost of pollution) does not necessarily lead to more environmental innovation. In our paper, investing in abatement also reduces the emission to output ratio and emissions are also proportional to output, making the marginal abatement cost curves also cross. A key difference between our contribution and theirs is that we endogenise the tightening of regulation by introducing an intrinsically motivated buyer (the environmental group). The higher the weight that the environmental group gives to the purchase of permits, the more permits the environmental group will withdraw from the ETS. This, in turn, increases the permit price, thereby making polluting more costly for the firms; the same effect that a more stringent environmental policy would have in the above mentioned contributions. Thus, our result in Proposition 3.i. can be seen as complementary to those in the above mentioned papers, therefore contributing to an emerging body of literature which shows the existence of non-monotonicities in the investment incentives as a very general result arising in different contexts. Given the mechanisms inducing the U-shape, we are confident that the result presented in Proposition 3.i is robust and does not rely on the specific functional forms used in this paper.

Proposition 3.ii states that firms' emissions per unit of output will be higher with the environmentalist's participation in the ETS if z (that is, the extra weight they give to the reduction of emissions) is high enough. The participation of the environmentalists will lead to higher permit prices than if they were not participating. As a result, we have the two effects alluded to before: Reduction of emissions per unit of output (higher permit prices make the investment in abatement comparatively cheaper) and reduction of output (firms produce less because the increase in the price of permits implies an increase in their marginal cost of production). As z increases, the second effect becomes stronger reducing the incentives to invest in abatement. It follows that there is a value of z (z_l) which is high enough to induce firms to invest less in the abatement technology than they would have done in the absence of the environmentalists. Below this value of z, the participation of the environmentalists will induce cleaner production.[24]

The reader could be concerned about the robustness of the result in Proposition 3.ii, since the existence of z_l may not be guaranteed *a priori*. In Section 6, we seek to appease such concerns by undertaking a number of robustness checks (different functional form of the environmental damage function, changes in the objective function of the environmental group, etc.). The results indicate that the result in Proposition 3(ii) is robust to those alternative frameworks, thus suggesting that its relevance is not restricted to our current set-up. On the contrary, the same result can emerge under alternative scenarios. It should be noted, however, that further checks with more general functional forms could be a research avenue worth pursuing.

Figure 1 illustrates Proposition 3. Firms' emissions to output ratios are depicted as a function of z. The horizontal line represents firms' emissions per unit of output in the absence of the environmental group from the ETS. For $z > z_l$, firms invest less in the abatement technology in the presence than in the absence of the environmentalist, leading to higher emissions per unit of output. At this point the reader may wonder about the different regions (0 to 4) identified in the figure. These will be explained in the next section of our paper, where we compare the equilibrium outcomes in terms of output and emissions levels across the two cases.

[Insert Figure 1 about here]

5 Comparison of Output and Emissions Levels

First, it is important to notice that for a given k, firms cannot produce more when the environmentalists are allowed to participate than when they are not. The same applies to emissions. The following lemma explains.

Lemma 3 *For a given k, then, $q^*_{i,G} \leq q^*_{i,NG}$ and $y^*_{i,G} \leq y^*_{i,G}$.*

[24] We can illustrate this result with a numerical example. Take the case of $a = 1.5$ and $\gamma = 1$, the emissions per unit of output in equilibrium is $k^*_{NG} = 0.830$. The presence of the environmental group would render higher emissions per unit of output (k higher than 0.830) for $z > 1.17$.

However, as the participation of the environmental group in the permit market will influence firms' investment in the abatement technology, it is necessary to go beyond the analysis of output and emissions levels for given values of k. Earlier we have shown that for $z > z_l$ firms will invest more in abatement in the presence of the environmentalists than in their absence, that is $k^*_G > k^*_{NG}$. As a consequence of this, and given that the equilibrium output levels are decreasing in k, we can state the following.

Proposition 4: *The following holds,*

i) $q^*_{i,G} \lesseqqgtr q^*_{i,NG}$ if $z \leq z_l$.

ii) $q^*_{i,G} < q^*_{i,NG}$ *if* $z > z_l$.

From proposition 3.ii and proposition 4 we know that the participation of an environmental group in the ETS can induce firms to invest more to reduce their emissions per unit of output and simultaneously reduce their output levels as long as the weight they give to the purchase of permits (z) is not too high. However, if z is high enough ($z > z_l$), firms will invest less in cleaning up their production than they would do in their absence. This last observation (proposition 4.ii) does not imply that the emissions levels by firms i and j would actually increase if the environmentalists were characterized by high z. In fact, proposition 4.ii emphasizes the existence of a trade-off between the level of investment in abatement and the level of output for higher z. Firms i and j's total emissions levels decrease despite lower investment in abatement due to the lower levels of production.[25]

The different situations in terms of the effects of the participation of the environmental group in the ETS are also illustrated in Figure 1. Recall that firms' emissions to output ratios are depicted as a function of z (that is, the extra weight given by the environmental group to the reduction of emissions) and that the horizontal line represents firms' emissions per unit of output in the absence of the environmental group from the ETS. For very low values of z (region 0 in the figure), a corner solution arises where the

[25] Continuing with the same example as before ($a = 1.5$, $\gamma = 1$), we know that without the environmentalists, we have $k^*_{NG} = 0.83$, $q^*_{i,NG} = 0.37$ and $y^*_{i,NG} = 0.31$. Now assume that the environmentalists participate in the ETS and that z is relatively large, for example, $z = 2$ (recall that $z_l = 1.17$). Then, firms invest less in abatement ($k^*_G = 0.87$) but also produce less, ($q^*_{i,G} = 0.18$), rendering lower emissions levels ($y^*_{i,G} = 0.16$).

environmentalists choose not to participate in the permit market despite being allowed to. Thus, the equilibrium outcomes are the same whether the environmentalists are allowed or not allowed to participate in the ETS. For relatively low values of z (region 1), the presence of the environmental group induces more investment in abatement leading to a lower emissions to unit of output ratio but higher output levels. Total emissions are higher in the presence of the environmentalists than in their absence. For intermediate values of z (region 2), the environmental group demands a larger amount of permits, affecting the permit price more heavily. As a consequence, firms invest more in abatement. Despite increasing output, total emissions are lower with the participation of the environmental group due to the lower emission to output ratio. In this case, the participation of the environmental group induces cleaner production, more output and lower total emissions. For higher values of z (region 3), the environmental group would tend to withdraw even more permits. As a consequence, firms invest more in abatement but they also reduce their production levels. Overall, this renders a decrease in their emissions levels. Finally, for even higher values of z (region 4), the participation of the environmental group induces firms to reduce output so much that they do not have incentives to invest in abatement. Total emissions will be lower than without the environmentalists' participation but this will solely come as a consequence of a reduction in output.

All in all, allowing an environmental group to participate could improve the equilibrium outcomes both in terms of emissions and output levels. In particular, if the (extra) weight given by the environmental group to the wihdrawal of permits is not too high or too low (region 2), technological improvements, higher output and lower emissions would be attained. However, for lower and higher values of this weight, the participation of the environmental group would bring about the trade-off between emissions and output levels.

6 Robustness checks and extensions

In this section we discuss some of the robustness checks we have conducted to test the sensitivity of our results to some of our modelling assumptions; particularly the functional form of the externalities, the objective function of the environmentalists and the existence of competition in the output markets. Given the previous findings in the literature, we can anticipate that as long as emissions are proportional to output and investing in abatement leads to a lower emission to output ratio, the non-monotonicities in the abatement incentives (Proposition 3.i) will still arise. These extensions allow us to discuss in which way some of our other results are affected by the different modifications in the modelling; in particular, our result in Proposition 3.ii.[26]

6.1 Functional form of the externalities

Both quadratic and linear functions have been widely used to model externalities in the theoretical literature. In this paper, we have opted for a linear form out of simplicity. To test whether this functional form affects our results, we have also solved our model using a quadratic function to model the environmental damage; in particular $E = \left(\sum_{i=1}^{2} k_i q_i\right)^2$.

As expected, the result that k_G^* is U-shaped in z still arises with this alternative modelling of the externalities. Moreover, we have also checked that with quadratic externalities there might be a value of z ($z_l \geq 0$) beyond which firms will invest less in the abatement technology with the environmentalists than without the environmentalists ($k_G^* > k_{NG}^*$). The change in modelling only affects how far from the origin the critical values of z are. All in all, our main qualitative results remain the same.

6.2 Objective function of the environmentalists

We have solved the model with two other alternative objective functions of the environmental group. In particular, we have checked whether our results are robust to the environmentalists taking into account other elements too. For example, we have explored whether our results change when the environmental group also care about consumer surplus (that is, they do not act solely as "citizens", they also have consumption concerns). In such a case, the environmental group's objective function can be written as $\Omega = -E + zx + m + CS$. Furthermore, we have also solved the model for the case where the environmental group also includes producer surplus as part of its objectives (that is, total surplus is part of their objective function). In such a

[26] More details available upon request.

case, the environmental group maximizes the following $\Omega = -E+zx+m+TS$, where $TS = CS + \sum_{i=1}^{2} \pi_i$.

In both these cases, the environmental group tends to withdraw fewer permits than in our benchmark case. The reason for this is that CS and TS crucially depend on output and the number of permits withdrawn by the environmentalists affects output negatively. In both cases, the equilibrium k will be U-shaped in z and there will be a degree of impure altruism beyond which firms will invest less in abatement in the presence of the environmentalists than in their absence. As before, although the critical values of z which make k_G^* turn increasing in z and $k_G^* > k_{NG}^*$ may differ across cases, the qualitative results regarding the equilibrium k remain the same than in our benchmark model.

Finally, one could argue that it may be realistic to assume that the weight given to the reduction of permits is higher if total emissions are higher. To test whether this would affect our results, we have also solved our model in the case where z is increasing in total emissions. That is $z = \alpha(y_1 + y_2)$. Thus, the objective function of the environmental group would be written as $\Omega = -E + \alpha(y_1 + y_2)x + m$.

It is possible to show that the U-shape function of k_G^* still arises, in this case with respect of α. We have also checked that the presence of the environmental group in the ETS may also result in higher emissions per unit of output ($k_G^* > k_{NG}^*$) for high enough values of α.

6.3 Product market competition

We have also solved the model where there are n firms competing both in the permit market and in the output market. In this case, firms faces a linear inverse demand function $P_i = a - q_i - \gamma \sum q_j$ and the price of permits is $R = x + \sum k_i q_i$ with $i, j \in 1...n$ and $i \neq j$. The parameter γ describes the degree of product differentiation, ranging from 0 (independent goods) to 1 (homogenous goods). Setting $\gamma = 1$ and $n = 2$ yields the model and results presented in the main sections of the paper.

In the final stage, the FOC for each firm yields:

$$\frac{\partial \pi_i}{\partial q_i} = a - 2q_i - \gamma \sum q_j - 2k_i^2 q_i - k_i \sum k_j q_j - xk_i = 0. \tag{24}$$

The FOC for maximization for the environmental group is:

$$\frac{\partial \Omega}{\partial x} = z - 2x - \sum k_i q_i = 0 \tag{25}$$

Solving the system of FOC for maximization for the firms in (17), we obtain firm i's reaction function:

$$q_{i,G}^R = \frac{a - \gamma \sum q_j - k_i \sum k_j q_j - k_i x}{2(1 + k_i^2)}. \tag{26}$$

Firms' outputs are strategic substitutes due not only to output market competition (where $\gamma \neq 0$) but also to competition in the ETS. Furthermore, firm i's output and the number of permits withdrawn by the environmentalists are also strategic substitutes. As before, this relationship is stronger, the more polluting firm i's production is.

As explained in the main sections of this paper, in order to analyze the behavior of the environmental group, it is sufficient to analyze x_G^* in symmetry. Solving the system of FOCs and applying symmetry yields

$$x_G^*|_{k_i=k_j=k} = \begin{cases} \frac{z(2+\gamma(n-1)+k^2(1+n))-ank}{2(2+\gamma(n-1)+k^2)+nk^2} > 0 & if \ \frac{a}{z} < \frac{(2+\gamma(n-1)+k^2(1+n))}{nk} \\ 0 & otherwise \end{cases} \tag{27}$$

Interestingly, n affects negatively while γ affects positively the number of permits withdrawn by the environmental group. That is, $\frac{\partial x_G^*}{\partial n} < 0$ and $\frac{\partial x_G^*}{\partial \gamma} > 0$. The intuition is as follows: Even though the opposite applies to individual output, aggregate output is increasing in n. Other things being equal, higher aggregate output implies that more permits are demanded. Thus, more firms in the market translates into higher permit prices, which, in turn, reduces the number of permits demanded by the environmental group.

In contrast, higher γ implies less aggregate (and individual) output. The intuition for this can be seen if we compare what happens at the extremes ($\gamma = 0$ and $\gamma = 1$): If goods are independent ($\gamma = 0$), essentially there are two separate markets. In contrast, if goods are homogenous ($\gamma = 1$), firms' share one market. As a consequence, as γ increases, fewer permits are demanded by firms, lowering the permit price and making the environmental group more able to buy permits and affect their prices.

We have verified that the non-monotonicities in the abatement incentives derived from the presence of the environmental group still arise with competition in the product market and that $k_G^* > k_{NG}^*$ may happen for sufficiently large values of z. However, given that, *ceteris paribus*, the environmental group tends to withdraw fewer permits for large n and low γ, the effect of the environmental group's actions on the price of permits and therefore on firms' choices will be less strong for markets characterised by a large number of firms and with high degrees of product differentiation. Although the non-monotonicities in k_G^* still arise in such markets, the gap between k_G^* and k_{NG}^* will be smaller the larger n and the lower γ are. Thus, if the policy maker is concerned about the potential detrimental effects of the participation of environmental groups in ETS on firms' incentives to invest in abatement, she should pay particular attention to markets characterised by a relatively small number of firms and low product differentiation, at least according to the results in our setting.

7 Conclusions and Discussion

In this paper we have examined the participation of an environmental group in the Emissions Trading System (ETS) and its effects on firms' abatement choices. We have analyzed the case where there are two oligopsonist firms in the ETS which can invest in an integrated abatement technology to reduce their emissions per unit of output.

We have shown that firms purchasing permits in the ETS tend to produce less the lower their emissions per unit of output are. Moreover, large market sizes and low abatement technology costs favor investment in abatement, both with and without the presence of the environmental group in the ETS. Furthermore, firms' decisions on output are strategically interdependent even when firms do not compete in the final output market.

The participation of the environmental group, pushing the price of permits up, has two effects: First, firms invest in abatement to reduce their emissions per unit of output. And second, firms reduce their output levels. The latter effect will render investment in abatement less profitable. Given that the higher the weight the environmental group gives in its objective function to the reduction of emissions (or, the more impurely altruistic the environmental group is, in a possible interpretation of our modelling), the more permits they tend to purchase, firms' incentives to invest in the abatement technology are not monotonically increasing in this weight. Instead, the interplay between the two effects above is crucial.

Our results show that firms' emissions per unit of output are U-shaped in the weight given by the group to the withdrawal of permits. For higher degrees of this weight, the presence of the environmental group in the ETS could induce firms to invest less in abatement, thereby leading to higher emissions per unit of output. However, firms also produce less output, rendering lower total emissions. For lower values of this weight, the participation of the environmental group induces more investment in abatement but also higher output levels. This can therefore lead to higher total emissions in the presence of the environmentalists than in their absence. For intermediate values of this weight, the participation of the environmental group will lead to technological improvements, higher output and lower emissions. Thus, we can state that allowing an environmental group to participate could improve the equilibrium outcomes both in terms of emissions and output levels. However, this requires that the weight given by the environmental group to the reduction of emissions is not too high or too low.

We have conducted a number of checks to test the robustness of our results to changes in the objective function of the environmental group. In particular, including consumer or even producer surplus into the objective function of the environmentalists does not affect qualitatively any of them. Moreover, we have verified that our results can still arise if the weight given to the withdrawal of permits is increasing in total emissions. Therefore, we can conclude that it is far from clear that the participation of third parties in an ETS will necessarily induce technological improvements or lead to lower emissions levels. Although we acknowledge that it may be difficult to have precise information regarding the preferences or motivations of an environmental group or any other third party, we argue that the policy maker or regulator should be aware of this potential problem, particularly in markets with a small number of firms or low degrees of product differentiation, where the environmental group will tend to withdraw a larger number of permits.

The reader should bear in mind that we have not attempted to provide a complete welfare analysis of the presence of the environmental group in the ETS. Such an analysis would require to weigh output (and hence consumer and producer surplus) versus environmental damage. A valuation of environmental damage versus surplus would need to be drawn from the specific preferences of the policy-maker or society as a whole. This could constitute an avenue for future research.

Our results have been derived in a streamlined context. Further research would be certainly welcome. In particular, it would be worthwhile to study the participation of more than one third party in the ETS, where free-riding problems could arise. It would also be interesting to allow for more general demand and cost functions, different industry structures and/or permit market arrangements and the interaction with other environmental and industrial policy tools.

It is worth noting that in this paper we have not contemplated alternative ways in which the environmental group could affect firms' behavior. For example, the environmental group could choose to pay firms directly to reduce their emissions. However, as long as there is more than one firm in the ETS, such action could be less cost-effective for the environmental group than the direct participation in the ETS because it would involve multiplying their expenditure (paying each of the firms) to achieve the same target. Moreover, if the environmental group chooses to pay only one of the two firms to reduce its emissions, it would make polluting cheaper for the other firm, as it would alleviate the pressure on the price of permits. The overall effect of such actions in terms of investment in abatement and pollution is therefore unclear and could constitute another avenue for further research.

8 Appendix: Proofs

Lemma 1

Proof. It is immediate to see that the denominator in (14) is positive. Therefore, the sign of $\frac{\partial q^*_{i,NG}}{\partial k_i}$ is determined by the sign of the numerator in (14). Given that $k_i, k_j \in (0,1)$,both $k_j(4(1+k_j^2)+k_i^2(4+3k_j^2))$ and $2k_i(4+3k_j^2)((2-k_ik_j+2k_j^2)))$ are positive. As $a>0$, the numerator in (14) is negative. As a consequence, we know that $\frac{\partial q^*_{i,NG}}{\partial k_i}<0$. ■

Proposition 1

Proof. Focusing on $\gamma > 0.34a^2$, we know that $\frac{\partial \pi_i}{\partial k_i}$ is strictly decreasing in k for $\forall k \in (0,1)$. Moreover, it is easy to check that $\frac{\partial \pi_i}{\partial k_i}$ is continuous and in symmetry, $\lim_{k\to 0}\frac{\partial \pi_i}{\partial k_i}=2\gamma>0$ and $\lim_{k\to 1}\frac{\partial \pi_i}{\partial k_i}=-\frac{46a^2}{375}<0$. Thus, $\frac{\partial \pi_i}{\partial k_i}$ moves from positive to negative and can only cross the horizontal axis once in $k\in(0,1)$. Thus, we can state that, there is one and only one root in $k\in(0,1)$. We will use the implicitly function theorem to characterize this root.

The FOC implies $\frac{\partial \pi_{i,NG}}{\partial k_i}=0$. Using the implicit function we know that:

$$\frac{\partial k^*_{i,NG}}{\partial a}=-\frac{\frac{\partial(\frac{\partial \pi_{i,NG}}{\partial k_i})}{\partial a}}{\frac{\partial(\frac{\partial \pi_{i,NG}}{\partial k_i})}{\partial k_i}} \text{ and } \frac{\partial k^*_{i,NG}}{\partial \gamma}=-\frac{\frac{\partial(\frac{\partial \pi_{i,NG}}{\partial k_i})}{\partial \gamma}}{\frac{\partial(\frac{\partial \pi_{i,NG}}{\partial k_i})}{\partial k_i}}, \tag{a.1}$$

or rearranging,

$$\frac{\partial k^*_{i,NG}}{\partial a}=-\frac{\frac{\partial \pi_{i,NG}}{\partial k_i\partial a}}{\frac{\partial^2 \pi_{i,NG}}{\partial k_i^2}} \text{ and } \frac{\partial k^*_{i,NG}}{\partial \gamma}=-\frac{\frac{\partial \pi_{i,NG}}{\partial k_i\partial \gamma}}{\frac{\partial^2 \pi_{i,NG}}{\partial k_i^2}}. \tag{a.2}$$

As stated before, given $\gamma>0.34a^2$, $\frac{\partial^2 \pi_{i,NG}}{\partial k_i^2}<0$. Thus, it is easy to see that $\frac{\partial k^*_{i,NG}}{\partial a}$ and $\frac{\partial k^*_{i,NG}}{\partial \gamma}$ have respectively the same signs as $\frac{\partial \pi_{i,NG}}{\partial k_i\partial a}$ and $\frac{\partial \pi_{i,NG}}{\partial k_i\partial \gamma}$. Next, we must check the signs of $\frac{\partial \pi_{i,NG}}{\partial k_i\partial a}$ and $\frac{\partial \pi_{i,NG}}{\partial k_i\partial \gamma}$.

After calculating $\frac{\partial^2 \pi_{i,NG}}{\partial k_i\partial a}$, we substitute k_i and k_j by k. This yields $\frac{\partial \pi_{i,NG}}{\partial k_i\partial a}$ in symmetry, which is positive for any $k\in(0,1)$

$$\left.\frac{\partial^2 \pi_{i,NG}}{\partial k_i\partial a}\right|_{k_i=k_j=k}=\frac{-4ak(6+11k^2+6k^4)}{(2+k^2)(2+3k^2)^3}<0. \tag{a.3}$$

On the other hand, $\frac{\partial^2 \pi_{i,NG}}{\partial k_i\partial \gamma}$ is obviously positive

$$\frac{\partial^2 \pi_{i,NG}}{\partial k_i\partial \gamma}=2(1-k_i). \tag{a.4}$$

We therefore know that $\frac{\partial k^*_{i,NG}}{\partial a}<0$ and $\frac{\partial k^*_{i,NG}}{\partial \gamma}>0$. Therefore, $k^*_{i,NG}$ is decreasing in a and increasing in γ. ■

Proposition 2

Proof. It follows immediately from the analysis of $\frac{z(2+3k^2)-2ak}{4(1+k^2)}$. ■

Lemma 2

Proof. Consider the case where $x^*_G > 0$. First, we substitute $x^*_G > 0$ into $q^*_{i,G}$ and calculate$\frac{\partial q^*_{i,G}}{\partial k}$. This derivative evaluated in symmetry can be written as $\frac{\partial q^*_{i,G}}{\partial k} = \frac{-ak(7+5k^2)-(2-k^4)z}{4(1+k^2)^2(2+k^2)}$.Given that k lies within the interval $(0,1)$, it is clear that $\frac{\partial q^*_{i,G}}{\partial k} < 0$. Now consider the case where $x^*_G = 0$. in that case, $q^*_{i,G} = q^*_{i,NG}$, which is also decreasing in k, as we know from Lemma 1. The rest of the lemma follows. ■

Proposition 3

Proof. Part i. Focusing on $\gamma > 0.34a^2$, we know that $\frac{\partial \pi_i}{\partial k_i}$ is strictly decreasing in k for $\forall k \in (0,1)$.It is easy to check that $\frac{\partial \pi_i}{\partial k_i}$ is continuous and that, in symmetry, $\lim\limits_{k\to 0} \frac{\partial \pi_i}{\partial k_i} = 2\gamma - \frac{az}{4} > 0$ given that $\gamma > 0.34a^2$ and $z < 2a$. Moreover, $\lim\limits_{k\to 1} \frac{\partial \pi_i}{\partial k_i} = -\frac{1}{48}(2a-z)(3a+2z) < 0$ since $z < 2a$. Thus, $\frac{\partial \pi_i}{\partial k_i}$ moves from positive to negative and can only cross the horizontal axis once in $k \in (0,1)$. Thus, we can state that, there is one and only one root in $k \in (0,1)$ along the symmetric path. Using the implicit function theorem, we will characterize this root, $k^*_i(z)$.

The slope of the function $k^*_i(z)$ is given by $\frac{\partial k^*_i}{\partial z} = -\frac{\frac{\partial^2 \pi_{i,G}}{\partial k_i \partial z}}{\frac{\partial^2 \pi_{i,G}}{\partial k_i^2}}$. As stated before, given $\gamma > 0.34a^2$, $\frac{\partial^2 \pi_{i,G}}{\partial k_i^2} < 0$. Therefore, the sign of $\frac{\partial k^*_i}{\partial z}$ depends on the sign of $\frac{\partial^2 \pi_{i,G}}{\partial k_i \partial z}$: If it is positive (negative), then $\frac{\partial k^*_i}{\partial z} > (<) 0$. After calculating $\frac{\partial^2 \pi_{i,G}}{\partial k_i \partial z}$, we substitute k_i and k_j by k, yielding

$$\left.\frac{\partial^2 \pi_{i,G}}{\partial k_i \partial z}\right|_{k_i=k_j=k} = \frac{-a(4-3k^2)+4kz}{8(2+3k^2+k^4).}, \tag{a.5}$$

It is easy to check that the denominator in $\frac{\partial^2 \pi_{i,G}}{\partial k_i \partial z}$ is positive and therefore, the sign of $\frac{\partial^2 \pi_{i,G}}{\partial k_i \partial z}$ depends only on its of the numerator. Solving $-a(4-3k^2)+4kz = 0$, we can find the critical value of z, z_h above (below) which $\frac{\partial^2 \pi_{i,NG}}{\partial k_i \partial z}$ is positive (negative). As a consequence, if $z > (<)\ z_h$, $\frac{\partial k^*_i}{\partial z} > (<) 0$. This critical value is $z_h = \frac{a(4-3k^2)}{4k}$. It is easy to check that, z_h is increasing in a.

Part ii. It follows from the functional forms of k_G^* and k_{NG}^*. ■

Lemma 3

Proof. We know that the equilibrium output will be higher if $x = 0$ than is if $x > 0$, given that $\frac{\partial q_i^*}{\partial x} < 0$. The output level for $x = 0$ is the same as the output level in the absence of the environmentalists. It follows that $q_{i,G}^* \leq q_{i,NG}^*$. Further, recall that the emissions levels in market i are given by $y_i = k_i q_i$. Thus, for a given k, higher output can only imply higher emissions. The rest of the lemma follows. ■

Proposition 4

Proof. It follows from the functional forms of k_G^*, k_{NG}^* and lemmata 1, 2 and 3. ■

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Figure 1: Emissions per unit of output with and without the environmentalists' participation.