Technological choice under environmentalists’ participation in Emissions Trading Systems

Elias Asproudis†
Dpt Economics
Loughborough University

Maria José Gil-Moltó‡
Dpt Economics
University of Leicester

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Abstract

We model competition in emissions tradable system as a game between two firms acting as duopsonists in an input market. In a previous stage, technology is endogenized as the result of a simultaneous move game between the two firms. We focus on the role of an environmental group on the resulting Nash equilibrium. Firms choose more "polluting" technologies in the presence than in the absence of the environmentalists in the ETS, if the environmentalists are characterised by low or high degrees of impure altruism. For intermediate values of impure altruism, the presence of the environmentalists induces firms to adopt "greener" technologies.

†Elias Asproudis gratefully acknowledges the financial support received from Loughborough University, where he is conducting his PhD studies.
‡m.j.gil-molto@le.ac.uk; Dpt Economics, University of Leicester, Leicester, LE1 7RH (United Kingdom).
1 Introduction

Emissions trading systems (ETS 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 on the creation of economic incentives to reduce pollution through the exchange of permits. The regulator sets a maximum amount of emissions, or target, and distributes permits among the agents in the market up to the point where the total amount of distributed permits equals the target. In such a setting, the agents who generate more emissions than the permits they have allocated need to buy permits and those whose permit allocations exceed their emissions can sell permits.

Following the Kyoto Protocol (1998) the ETS have become major tools in the anti-pollution policy in a number of countries. For example, the European Union adopted the ETS using a grandfathered system to distribute the permits.\(^1\) In the US, there are ETSs in place for the reduction of SOx and NOx emissions. Interestingly, the access to many of the Emissions Trading System is open not only to firms but also to third parties, such as citizens, consumers, environmental organizations, other types Non Governmental Organizations, etc. An example of this can be found in the US sulfur emissions trading program. In other words, both polluters and victims can participate in the ETS and their interaction will determine pollution levels.

The reasons why the thirds should be allowed to participate and why they should be interested in participating have been the focus of a number of contributions in the economics literature. For example, Smith and Yates (2003a, 2003b) and Shrestha (1998) show that the thirds’ participation in the permits’ market gives valuable information to the regulator regarding the market equilibrium when the regulator faces uncertainty: If third parties purchase permits, it must be that the initial number of permits was higher.

\(^1\) According to the grandfathered distribution system, the regulator distributes permits to the firms based on the firms’ historical emissions.
than the optimum. Also regarding the regulators’ uncertainty, English and Yates (2007) design an expansion on the Kwerel’s mechanism. In their setting, the pollution’s damage is common knowledge but the firm’s abatement cost is private. The regulator asks the firms about their abatement cost. The authors show that the Kwerel’s mechanism may be effective only if the citizens take part in the ETS.\(^2\) Malueg and Yates (2006) show that the citizens may prefer to participate in the permits’ market under a grandfathered system instead of lobbying the regulator to reduce the total number of allocated permits.

There is already some empirical evidence on the presence of the thirds in ETS and its effects. Schwarze and Zapfel (2000) document the thirds participation in permits markets in two different anti-pollution programs, the Sulfur Allowance Trading Program (SAT) and the Regional Clean Air Incentives Market (RECLAM, for the reduction of SOx and NOx levels). Joskow et al. (1998) showed that third parties offered too high prices in the auctions of SO\(2\) permits in the 90s. Further, it seems that the thirds participation in the sulfur emissions trading program has not been very intensive. For example, Israel (2007) examines the thirds’ participation (mainly environmental groups) between the years 1993 and 2006, concluding that the number of withdrawn permits is not very high relative to the total number of permits. One could interpret this fact as an indication of the limited efficacy of the presence of the thirds in the ETSs. However, the above fact could also be interpreted as an indication that the US Environmental Protection Agency had targets close to the social optimal.

The objective of our paper is to study the interaction of firms and environmental groups in ETS and the implications of this for firms’ technological choices. The literature on ETS has already shown the linkages between the existence of ETSs and the degree of technological change. For example,

\(^2\)Recently, Rousse (2008) also highlights the advantages of the direct participation in the carbon emissions trading systems.
Newell et al. (1999) and Popp (2002) analyze how the higher energy prices induce a higher technological innovation. In the same spirit, Kennedy (1999) argues that the regulator can reduce the quantity of available permits as a way to generate incentives for firms to adopt a greener technology even in the presence of uncertainty about the environmental damages. Fischer et al. (2003) and Requate and Unold (2003) compare the propensity to technological innovation generated by several market-based instruments and Kerr and Newell (2003) show that ETSs provide more efficient incentives for green technology adoption than taxes.\(^3\) Interestingly, the literature on ETS and technology choice has largely overlooked the implications of thirds’ participation in ETSs for firms’ technological choice, despite the relevance of this issue for environmental policy.

In our paper, we introduce a duopsony that must purchase permits in an ETS. The firms can choose the type of production technology they will use. The technologies available to firms differ in their environmental credentials and their set-up or adoption costs. The more polluting the production technology is, the more permits the firm requires per unit of output but also the lower the adoption cost. Further, we allow an environmental group to purchase (and therefore withdraw) permits from the market. The price of the permits will depend on the aggregation of the firms’ and the environmentalists’ demand of permits. It should be obvious that the higher the number of permits withdrawn by the environmentalists, the higher the permit prices and therefore, in principle, the more inclined firms will be to change to a greener technology. However, we also consider that the environmentalists are impurely altruistic. Andreoni (1989, 1990) emphasizes that people might be impurely altruistic and may obtain some gains in utility from charitable giving. The idea is that they might feel that they did something right or fair and this feeling increases their own utility (through self-satisfaction or

\(^3\)See also Goulder and Schneider (1999), Goulder and Mathai (2000), and Chakravorty et al. (1997).
warm-glow). In the spirit of Andreoni, we assume that the members of the group gain a non-material utility from withdrawing permits. This "impurely altruistic" behavior introduces a distortion in the market (as the environmentalists will tend to withdraw more permits than what would be socially optimal) and implies that a first best in emissions levels and technological choice will not be attained through the participation of the environmentalists. In the paper we will study how the emission levels and technological choice are affected by the environmentalists’ presence in the ETS and their degree of impure altruism and study the equilibrium outcomes with and without their participation.

Our results show that there is an inverted U-shape relationship between how polluting the chosen technology is and the degree of environmentalists’ impure altruism. Further, except for very low or very high degrees of impure altruism, firms will choose a greener technology in the presence of the environmentalists in the ETS than in their absence. As a consequence, if the objective of the policy-maker is to induce firms to adopt greener technologies, allowing an environmental group to participate in ETS is advisable except when they are characterised by very low or very high degrees of impure altruism.

The rest of the paper is structured as follows: In section 2 we present our model. In section 3 we analyse the case where the environmentalists are absent from the ETS. In section 4, we study the case of the environmentalists’ participation in the ETS. In section 5 we conduct some comparative static analysis regarding technology choices, emissions and output levels. Section 6 concludes.

2 The model

In our model, two monopolistic firms act as duopsonists in the permits’ market. Each firm faces a linear inverse demand function such as
\[ P_i = a - q_i \] (1)

where \( q_i \) is firm i’s level of output produced by firms. Prior to start producing, firms choose their manufacturing technology from a spectrum of available technologies which differ in the level of emissions derived from the production of each unit of output. Firms must buy permits to offset their emissions\(^4\). Thus, the choice of technology determines the number of permits required to produce each unit of output. We denote the number of permits required per unit of output by \( k \) and will use \( k \) to index the technologies available to firms. The greener (the more environmentally friendly) the technology is, the lower its associated \( k \). For the sake of simplicity and without loss of generality, we assume that \( k \in (0, 1) \). Consequently, even if a firm chooses a very "green" technology (\( k \) close to 0), it still needs to purchase some permits to cover its emissions.

The total number of emissions and, as a consequence, the total number of permits demanded by firm \( i \) depends on the type of technology (how polluting the technology is) and the level of output chosen by firm \( i \)

\[ y_i = k_i q_i \] (2)

We assume that the available technologies differ also in the investment required to adopt them

\[ F_i = \gamma (1 - k_i)^2 \] (3)

Our modelling of the technology costs implies that adopting a greener technology entails higher adoption costs than adopting a more polluting one.\(^5\)

\(^4\)One interpretation of our model is that the firms are new entrants to the market and they do not receive permits through grandfathering. An alternative interpretation is that, even with grandfathering, firms do not have enough permits with their initial allocation. The demand of permits would represent the extra permits needed above the initial allocation.

\(^5\)The case in which cleaner technologies are also less costly to adopt is less interest-
The innovation costs are assumed to be quadratic to reflect the existence of diminishing returns to investment.

For simplicity, we assume that firms do not incur in any other production costs than those derived from the acquisition of permits. Thus, firms profits can be written as follows

\[ \pi_i = P_i q_i - R y_i - \gamma(1 - k_i)^2 \] (4)

where \( R \) is the unit price of permits.

We assume that in the permits market there is a third player: an environmental group. The environmentalists can withdraw permits from the market by purchasing a number \( x \) of permits. This affects the equilibrium in the permits market and subsequently, firms’ technological choice. We assume that the environmentalists are impurely altruists, that is their behavior is (partly) driven by the maximisation of their own utility. The environmentalists’ maximize the sum of consumer and producers surplus (\( CS \) and \( PS \) respectively) minus the emissions (\( E \)) and the costs of withdrawing permits (\( Rx \)) plus the satisfaction or utility gained from withdrawing permits (\( zx \)). The Objective Function therefore is:

\[ O_{EG} = (CS + PS - E) - Rx + zx \] (5)

The last term in \( O_{EG} \) is related to the impure altruism which characterises the environmental group. In our model, the impure altruism is measured by a parameter, \( z \), which represents the utility gains experienced by the environmentalists from withdrawing one unit of permits. Our model is related to Ahlheim and Schneider (2002), as we also (implicitly) introduce the third parties’ preferences in our model. However, our contribution differs from theirs in that we consider competition for permits between the citizens and the firms, while they consider the case where the thirds, households, can only

\[ \text{ing to study as in such case, the incentives of firms would be aligned with those of the environment.} \]
sell permits.

As standard, PS is defined as the aggregation of firms' profits across the two markets

\[ PS = \sum_{i=1}^{2} \pi_i \]  \hfill (6)

and CS in equilibrium is given by

\[ CS = \sum_{i=1}^{2} \int_{0}^{q_i^*} (P_i - P_i^*) \]  \hfill (7)

We assume that there is one unit of externality produced per each unit of emissions.

\[ E = \sum_{i=1}^{2} y_i \]  \hfill (8)

From now on, we will use the term "emissions" as a synonym of "externalities" or "pollution".

The two firms and the environmental group purchase permits from the permits market. The price of permits, \( R \), is an increasing function of the number of demanded permits

\[ R = c + h(y_i + y_j + x) \]  \hfill (9)

The unit price of permits, \( R \), can be interpreted in our modelling as the equilibrium price of permits in the ETS market. In other words, we are implicitly modelling the supply of permits\(^6\). For the sake of simplicity, we

\(^6\)The supply side would be composed by those firms that have already acceptable clean technology. They could be firms in other markets or even located in other countries with emissions levels well below the targets. This could be the case of the countries from the Former Soviet Union (FSU), where the total quantity of the permits is far above that of the real emissions. The excess permits -up from the real emissions to the Kyoto targets- are called ‘hot air’. (Stevens and Rose, 2002; Bohringer and Vogt, 2003, 2004; Klepper and Peterson, 2005; Bohringer et al. 2006; Bernard et al. 2007).
normalise $c$ to 0 and $h$ to 1. Our modelling of the price of permits differs from those contributions which assume that firms are price-takers and also from those contributions, such as Boyd and Conley (1997) and Conley and Smith (2005), where firms can buy permits at personalized prices. Our model is suitable to represent situations in which a small number of firms are present in the market (say, for example, electricity companies) and therefore have some degree of market power but they have to buy permits from a centralised market.

The timing of the game is as follows: In the first stage, firms choose their production technologies.\textsuperscript{7} In the second stage, the environmentalists purchase permits. In the last stage, firms choose quantities (implicitly determining their demand of permits).\textsuperscript{8} We assume that firms choose simultaneously in stages 1 and 3. We solve the game by backwards induction to analyse the Subgame Perfect Nash Equilibrium (SPNE). For comparison purposes, we solve the model without the environmentalists’ participation (that is $x = 0$ and the game is reduced to stages 1 and 3).

In the last stage, firms choose their output levels in order to maximize their profits. The equilibrium level of output is given by\textsuperscript{9}

$$ q_i^* = \frac{a(2 - k_i k_j + 2k_j^2) - k_i(2 + k_j^2)x}{4(1 + k_j^2) + k_i^2 (4 + 3k_j^2)} \tag{10} $$

where $x = 0$ when the environmentalists are absent from the ETS. We denote with subscripts $G$ and $NG$ respectively the with and without the Environmentalists participation in the ETS.

\textsuperscript{7}Technology choices are long term decisions. Therefore, it seems plausible to assume that these decisions take place in the stage preceding competition in the ETS and output markets.

\textsuperscript{8}Reducing the second and third stages to a single stage where firms and environmentalists take decisions simultaneously does not alter qualitative our results but complicates substantially the calculations.

\textsuperscript{9}Second order conditions for a maximum are fulfilled.
3 The environmentalists do not participate in the ETS market

In this section, we find the equilibrium of the game when the environmentalists are absent from the ETS market. As discussed above, without the participation of the environmentalists in the ETS, the equilibrium level of output is reduced to

\[ q_{i,NG}^* = \frac{a(2 - k_i k_j + 2k_j^2)}{4(1 + k_j^2) + k_i^2(4 + 3k_j^2)} \]  \hspace{1cm} (11)

It is tedious but easy to check that for any values of \( k_i \) and \( k_j \) between 0 and 1, that is the derivative of \( q_{i,NG}^* \) with respect to \( k_i \),

\[ \frac{\partial q_{i,NG}^*}{\partial k_i} = \frac{a(-k_j(4(1 + k_j^2) + k_i^2(4 + 3k_j^2)) - 2k_i(4 + 3k_j^2)((2 - k_i k_j + 2k_j^2)))}{4(1 + k_j^2) + k_i^2(4 + 3k_j^2)}, \]  \hspace{1cm} (12)

is negative. Interestingly, the more polluting the technology used by firms is, the less they produce. The intuition for this is that as \( k_i \) increases, firms require more permits to produce the same level of output. Furthermore, as a consequence of this, the price of permits increases (due to more permits being demanded). This increases firm \( i \)'s marginal cost of production, leading firm \( i \) to decrease its output.

Remark 1 Firms produce more, the less polluting their production technology is.

Substituting \( q_{i,NG}^* \) and \( q_{j,NG}^* \) into firms’ profit maximising and rearranging yields

\[ \pi_i(q_{i,NG}^*) = (1 + k_i^2)(q_{i,NG}^*)^2 - \gamma(1 - k_i)^2 \]  \hspace{1cm} (13)
In the first stage, firms choose \( k_i \) to maximise their profits. The first order condition yields

\[
\frac{\partial \pi_i}{\partial k_i} = 2k_i(q^*_{i,NG})^2 + 2(q^*_{i,NG})\frac{\partial q^*_{i,NG}}{\partial k_i}(1 + k_i^2) + 2\gamma(1 - k_i) = 0 \tag{14}
\]

In this paper, we focus on the symmetric solution \( k_i = k_j = k \). The FOC evaluated in symmetry are given by

\[
\frac{\partial \pi_i}{\partial k_i} = -2(\gamma(2 + 3k^2)^3(-2 + 2k - k^2 + k^3) + a^2k(6 + 11k^2 - 6k^4)}{(2 + k^2)(2 + 3k^2)^3} = 0 \tag{15}
\]

It can be easily checked that the SOC for a maximum\(^{10} \) holds for any \( k \in (0, 1) \) for \( \gamma > 0.08601a^2 \). From now on, we assume that \( \gamma \) and \( a \) take values that fulfill this inequality so that to guarantee the existence of interior solutions.

**Condition 1:** \( \gamma \) and \( a \) take values such that \( \gamma > 0.08601a^2 \).

Using the implicit function theorem we can characterise the relationship between the equilibrium \( k \) in symmetry, \( k^*_{NG} \), and the parameters of the model, \( a \) and \( \gamma \). Our finding is the following\(^{11} \)

**Remark 2** \( k^*_{NG}(a, \gamma) \) is increasing in \( \gamma \) and decreasing in \( a \).

In other words, the higher \( \gamma \) and the lower \( a \), the more polluting firms’ technology will be in the absence of the environmentalists from the ETS. The intuition behind our result follows: The parameters \( a \) and \( \gamma \) are related to the profitability of the investment in a technology. Although the parameter \( \gamma \) is invariant with the technology choice, it magnifies the differences between the costs of adopting a clean or a polluting technology. In essence \( \gamma \) scales up

\(^{10} \frac{\partial^2 \pi_i}{\partial k_i^2} = -(2\gamma + \frac{2a^2(16 - 44k^2 - 168k^4 - 183k^6 - 72k^8)}{(2 + k^2)^2(2 + 3k^2)^4}) < 0 \)

\(^{11} \)The proof is available from the authors upon request.
the differences in the technology costs. As a consequence, the higher $\gamma$, the more expensive "cleaner" technologies (lower $k_i$) relative to "more polluting" ones (higher $k_i$).

The market conditions are also important to explain the technology adoption. The parameter $a$ is related to the size of the market. Higher $a$ indicates larger market sizes and therefore, higher profitability (other things being equal) of investing in a "greener" technology. Higher market sizes will lead to higher output levels (other things being equal). This, in turn, will lead to higher demand of permits and therefore higher permit prices. Given this, firms have a stronger incentive to invest in a "greener" technology. Figure 1 depicts the equilibrium $k, k^*_{NG}$, against the ratio $\gamma/a^2$. The reader can easily see that the equilibrium technology choice is more polluting (higher $k$), the higher the ratio $\gamma/a^2$.

4  The environmentalists participate in the ETS market.

In this section, we find the equilibrium of the game when the environmentalists are present in the ETS. The solution to the third stage of the game (output) is given by (10). Substituting $q^*_i$ into the environmentalists' objective function and rearranging yields

$$O_{EG} = \sum_{i=1}^{2} (1/2)(q^*_i)^2 + \sum_{i=1}^{2} [(1+k_i^2)(q^*_i)^2 - \gamma(1-k_i)^2] - \sum_{i=1}^{2} (k_i q^*_i) - Rx + zx$$

(16)

The environmentalists choose the number of permits to buy, $x$, in order to maximise their objective function, $O_{EG}$. This maximisation problem has a solution $x^*(k_i, k_j)$ which in symmetry, $(k_i = k_j = k)$ is\textsuperscript{12}

\textsuperscript{12}The expression for $x^*_{G,S}$ outside the symmetric path is available from the authors upon
\[ x^*_{G,S} = \frac{-10a(k + k^3) + (2 + 3k^2)(2z + k^2(2 + 3z))}{2(4 + 5k^2 + k^4)} \] 

(17)

Several interesting observations can be made from the above result. First, it can easily be seen that \( \frac{\partial x^*_S}{\partial a} < 0 \). This means that the optimal number of withdrawn permits is decreasing in the size of market. Although this result might sound counterintuitive, it can be easily understood if one takes into account the profitability of the investment in innovation. As discussed above, the higher \( a \) is, the more profitable investing on a less polluting technology is. Therefore, the higher \( a \), the less necessary it is to induce firms to adopt "greener" technologies by making permits more scarce. Second, the number of permits withdrawn by the environmentalists is increasing in their degree of impure altruism (\( \frac{\partial x^*_S}{\partial z} > 0 \)). In addition, the higher \( k \) (the less clean the chosen technologies are) the more rapidly the number of withdrawn permits, \( x \), increase with the degree of the environmentalists’ impure altruism. (\( \frac{\partial x^*_S}{\partial x} > 0 \)) In other words, the less green the technology chosen by firms are, the more the behavior of the impurely altruistic environmentalists is reinforced.

Substituting \( x^*(k_i, k_j) \) into the profit function and applying the FOC yields

\[ \frac{\partial \pi_i}{\partial k_i} = 2k_i(q^*_{i,G})^2 + 2(q^*_{i,G}) \frac{\partial q^*_{i,G}}{\partial k_i} (1 + k_i^2) + 2\gamma(1 - k_i) = 0 \] 

(18)

We focus again in the symmetric solution. In symmetry, \( q^*_{i,G} \) and \( \frac{\partial q^*_{i,G}}{\partial k_i} \) can be written as follows \(^{13}\)

\[ q^*_{i,G} = \frac{4a(1 + k^2) - 2k^3 - (2k + 3k)z}{2(4 + 5k^2 + k^4)} \] 

(19)

\(^{13}\)After substituting \( x^*(k_i, k_j) \) into \( q^*_i \), we have calculated its derivative with respect of \( k_i \). This derivative evaluated in symmetry is shown in (20).
\[
\frac{\partial q^*_i\theta}{\partial k_i} = -\frac{2k^2(16 + 18k^2 + 6k^3 - k^4) + \delta_1 - \delta_2}{2(2 + k^2)(4 + 5k^2 + k^4)^2}
\]

where \(\delta_1 = ak(12 + k^2(25 + 22k^2 + 9k^3))\) and \(\delta_2 = z(16 + k^2(56 + 52k^2 + 14k^4 - 3k^8))\). Unfortunately, the closed-form solution for the first order condition is very intricate, due to the high number of roots, including imaginary roots. However, there is a solution for \(\frac{\partial q^*_i\theta}{\partial k_i} = 0\) for each set of values of \(a, \gamma\) and \(z\). To facilitate the comprehension of our results, we show graphically the solution to the above equation for different sets of values of the parameters that meet the SOCs for a maximum. Given that we are interested in the relationship between firms’ technological choice and the environmentalists’ impure altruism, \(z\), we show graphically the equilibrium technology choice as a function of \(z, k^*_G(z)\), for several sets of values of \(a\) and \(\gamma\). In particular, we have chosen the following sets: \\(\{a = 1, \gamma = 1\}\), \\(\{a = 1.5 \text{ and } \gamma = 1\}\); \\(\{a = 1 \text{ and } \gamma = 1.5\}\) and \\(\{a = 1.5 \text{ and } \gamma = 1.5\}\). Figures 2.a to 2.d despict \(k^*_G(z)\) for those four sets of values of \(a\) and \(\gamma\). The figures show that there is a U-shape relationship between firms’ technology choice and the degree of the environmentalists’ impure altruism. More specifically, as \(z\) increases, firms will tend to invest in technologies that are less polluting (lower \(k\)) up until a critical point of \(z\), where increases in \(z\) will actually lead to investments in more polluting technologies. The following remark summarises.

\textbf{Remark 3} There is a U-shape relation between firms’ technology choice and the degree of the environmentalists’ impure altruism.

The intuition behind this result is the following: As \(z\) increases, the environmentalists tend to withdraw more permits from the market. This has two effects: First, firms tend to choose cleaner technologies, as the marginal cost of producing is higher due to the lower number of permits which are required per unit of output. Second, firms reduce their output levels (note that \(q^*_i\) is decreasing in \(x\)). As firms reduce their production levels, investment in cleaner technologies becomes less profitable. The interaction
between these two effects will determine the technology choice. For low levels of $z$ (consequently, the environmentalists withdraw a relatively low number of permits), the first effect dominates the second effect. For high levels of $z$ (consequently, the environmentalists withdraw a relatively high number of permits), however, the second effect dominates.

In the next section we compare the outcome of the environmentalists’ participation in the ETS with that corresponding to their absence in terms of technology choice, emissions and output.

5 Comparative Statics

In this section we compare the equilibrium level of emissions and technology choice across the two cases solved above, namely the ETS without the environmentalists’ participation and the ETS with the environmentalists’ participation.

5.1 Output and emissions levels and degree of impure altruism

In this subsection, we analyse the relationship between the degree of impure altruism ($z$) and the equilibrium levels of output and emissions. The equilibrium level of output is

$$q_{i,G}^* = \frac{(4a(1 + k_G^2) - 2k_G^{*3}) - (2k_G^* + 3k_G^{*3})z}{2(4 + 5k_G^{*2} + k_G^{*4})}$$ \hspace{1cm} (21)

which is calculated by substituting $x^*$ into (10), and evaluating $q_{i,G}^*$ in symmetry.

Before proceeding to analyse whether the output is increasing in $z$, it is relevant to show the relationship between the equilibrium output and the technology choice:
Remark 4 The equilibrium output level is decreasing in \( k \) for any value of \( z \).

**Proof.** \( \frac{\partial q_{i,G}^*}{\partial k_G} \) evaluated in symmetry can be written as \( \frac{\partial q_{i,G}^*}{\partial k_G} = \frac{-1}{2(4+5k^2+4k^4)}(t_1 + t_2) \), where \( t_1 = 8ak + 8z + k^2(24 + 26z) \) and \( t_2 = k^4(10 + 9z) - k^6(2 + 3z) \). Given that \( k \) lies within the interval \((0, 1)\), it is easy to see that \( t_2 > 0 \), and therefore \((t_1 + t_2) > 0\). As a consequence, \( \frac{\partial q_{i,G}^*}{\partial k_G} < 0 \). QED.

As a consequence, we can say that in both cases (with and without environmentalists’ participation), the equilibrium output is decreasing in \( k \). In other words, the more polluting the chosen technologies are, the less firms produce.

Regarding the analysis of the relationship between \( q_{i,G}^* \) and \( z \), it is important to notice that an increase in \( z \) will have two effects on \( q_{i,G}^* \), a direct effect and an indirect effect, through \( k_G^* \), given that \( k_G^* \) is a function of \( z \). That is

\[
\frac{dq_{i,G}^*}{dz} = \frac{\partial q_{i,G}^*}{\partial z} + \frac{\partial q_{i,G}^*}{\partial k_G^*} \frac{dk_G^*}{dz}
\]  

The analysis of the above decomposition results in the following remark:

**Remark 5** The equilibrium level of output when the environmentalists participate in the ETS may only be increasing in \( z \) for relatively low values of \( z \) iff

\[
\left| \frac{\partial q_{i,G}^*}{\partial k_G^*} \frac{dk_G^*}{dz} \right| > \left| \frac{\partial q_{i,G}^*}{\partial z} \right|.
\]

**Proof.** It is easy to see from (21), that holding \( k \) constant, \( \frac{\partial q_{i,G}^*}{\partial z} < 0 \). Further, from remark 4, we know that the equilibrium output is decreasing in \( k \). Lastly, as we have discussed in section 4, we know that \( k_G^* \) is U-shaped with respect to \( z \). All in all, \( \frac{dk_G^*}{dz} \) is necessarily negative for relatively low values of \( z \) and may be positive for relatively high values of \( z \) if and only if \( \left| \frac{\partial q_{i,G}^*}{\partial k_G^*} \frac{dk_G^*}{dz} \right| > \left| \frac{\partial q_{i,G}^*}{\partial z} \right| \). The rest of the remark follows.

Regarding emissions \( y_{i,G}^* = k_{i,G}^* q_{i,G}^* \) and its relationship with \( z \), we can also decompose the effect of \( z \) on \( y_{i,G}^* \) as follows
\[
\frac{dy_{i,G}^*}{dz} = \frac{\partial k_{i,G}^*}{\partial z} q_{i,G}^* + \frac{\partial q_{i,G}^*}{\partial z} k_{i,G}^*
\]

The analysis of the separate effects in \(\frac{dy_{i,G}^*}{dz}\) leads to the following remark:

**Remark 6** The total level of emissions may be increasing in \(z\) if

For low values of \(z\), \(\frac{\partial q_{i,G}^*}{\partial z} > 0\) and \(\left| \frac{\partial k_{i,G}^*}{\partial z} q_{i,G}^* \right| > \left| \frac{\partial k_{i,G}^*}{\partial z} q_{i,G}^* \right|\) or

For high values of \(z\), if \(\left| \frac{\partial q_{i,G}^*}{\partial z} k_{i,G}^* \right| < \left| \frac{\partial k_{i,G}^*}{\partial z} q_{i,G}^* \right|

**Proof.** We know that \(q_{i,G}^* > 0\) and \(k_{i,G}^* > 0\). Further, following remark 5, we know that \(q_{i,G}^*\) can only be increasing in \(z\) for relatively low values of \(z\). Further, \(\frac{\partial q_{i,G}^*}{\partial k_{i,G}^*}\) evaluated in symmetry can be written as \(\frac{\partial q_{i,G}^*}{\partial k_{i,G}^*} = \frac{-1}{2(4+5k^2+4k^4)}(t_1 + t_2)\), where \(t_1 = 8ak + 8z + k^2(24 + 26z)\) and \(t_2 = k^4(10 + 9z) - k^6(2 + 3z)\). Given that \(k\) lies within the interval \((0, 1)\), it is easy to see that \(t_2 > 0\), and therefore \((t_1 + t_2) > 0\). As a consequence, \(\frac{\partial q_{i,G}^*}{\partial k_{i,G}^*} < 0\). We also know that \(k_{i,G}^*\) has an inverted U-shape with respect to \(z\). Therefore for low to intermediate values of \(z\) (where \(\frac{\partial k_{i,G}^*}{\partial z} < 0\)), the level of emissions can be increasing in \(z\) if \(\frac{\partial q_{i,G}^*}{\partial z} > 0\) and \(\left| \frac{\partial q_{i,G}^*}{\partial z} k_{i,G}^* \right| > \left| \frac{\partial k_{i,G}^*}{\partial z} q_{i,G}^* \right|\). For high values of \(z\) (where \(\frac{\partial k_{i,G}^*}{\partial z} > 0\)), \(\frac{\partial q_{i,G}^*}{\partial z}\) could be positive and therefore the total level of emissions could be increasing in \(z\) if \(\left| \frac{\partial q_{i,G}^*}{\partial z} k_{i,G}^* \right| < \left| \frac{\partial k_{i,G}^*}{\partial z} q_{i,G}^* \right|\). QED.

### 5.2 Technology Choice with and without the Environmentalists’ Participation

As discussed above, figure 1 shows that the technology chosen by firms depends solely on the market size \((a)\) and the technology costs \((\gamma)\). Therefore, we can identify the technology chosen for each pair of values of \(a\) and \(\gamma\). We proceed by identifying the technology choice in the absence of the environmentalists under the sets of profitability conditions analysed in the previous section, that is for \(\{a = 1, \gamma = 1\}\), \(\{a = 1.5, \gamma = 1\}\), \(\{a = 1, \gamma = 1.5\}\) and \(\{a = 1.5, \gamma = 1.5\}\). The results are summarised in table 1.
Recall that firms’ technology choice in the presence of the environmentalists is depicted for each of those sets of values of \( a \) and \( \gamma \) in figures 2.a to 2.d (Note that when the environmentalists are present in the ETS, firms’ technology choice depends not only on \( a \) and \( \gamma \) but also on \( z \), that is the degree of the environmentalists’ impure altruism). For \( a = 1 \) and \( \gamma = 1 \), the equilibrium technology choice in the absence of the environmentalists is characterised by \( k^{*}_{NG} = 0.93335 \) (as shown in table 1). Comparing with figure 2.a, we can say that for relatively low and relatively high values of \( z \), firms’ technology choice is less polluting in the absence of the environmentalists than in their presence (\( k^{*}_{NG} < k^{*}_{G} \)). For intermediate values of \( z \), the contrary holds (\( k^{*}_{NG} > k^{*}_{G} \)). For \( a = 1.5 \) and \( \gamma = 1 \), the technology chosen in the absence of the environmentalists implies \( k^{*}_{NG} = 0.830472 \). From figure 2.b we can see again that the equilibrium technology in the presence of the environmentalists is less polluting than the one in their absence for relatively low and relatively high values of \( z \), while for intermediate values of \( z \) the opposite holds. The same applies to the cases shown in figure 2.c and 2.d.

It is interesting to note from the policy point of view that the presence of the environmentalists in the ETS can induce firms to adopt a "cleaner" technology. However, if the environmentalists are characterised by relatively low or relatively high degrees of impure altruism, their participation can actually lead to worse technological choices than those that would have been made in their absence. As discussed above, as \( z \) increases, the environmentalists tend to withdraw more permits from the market and this has two effects: Technology substitution and output reduction. As \( z \) increases, the second effect

<table>
<thead>
<tr>
<th>((a, \gamma))</th>
<th>(k^{*}_{NG})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1, 1)</td>
<td>0.933335</td>
</tr>
<tr>
<td>(1.5, 1)</td>
<td>0.830472</td>
</tr>
<tr>
<td>(1, 1.5)</td>
<td>0.956832</td>
</tr>
<tr>
<td>(1.5, 1.5)</td>
<td>0.895255</td>
</tr>
</tbody>
</table>

Table 1: Technology choice without environmentalists
becomes stronger reducing the incentives to invest on "cleaner" technologies. We summarise our results in this section in the following remark:

**Remark 7** The presence of the environmentalists may induce firms to adopt more polluting technologies for relatively low and high values of $z$. For intermediate values of $z$, however, their presence may induce the adoption of "cleaner" technologies.

### 5.3 Comparison of Emissions and Output Levels

In this section, we compare the equilibrium levels of output and emissions across the two cases (with and without the environmentalists’ participation in the ETS). First, it is important to notice that for a given $k$, firms produce more in the absence of the environmentalists. This also leads to a higher level of emissions. The following remark explains.

**Remark 8** The equilibrium output and emissions levels are higher when the environmentalists participate than when they do not participate for a given $k$.

**Proof.** We know that the equilibrium output will be higher if $x = 0$ than is if $x > 0$, given that $\frac{\partial q_i}{\partial x} < 0$. Recall that the emissions levels in market $i$ are calculated as $y_i = k_i q_i$. For a given $k$, therefore, the difference between the emissions levels with and without the environmentalists’ participation is determined by the difference in the equilibrium output levels. QED.

However, the participation of the environmentalists’ in the permits market will influence firms’ technological choice. As a consequence of this, it is necessary to go beyond the comparison of output and emissions levels for given values of $k$. In the previous section, we have discussed that firms will choose a more polluting technology in the absence than in the presence of the environmentalists for intermediate values of $z$ and that for low or high levels of $z$, the opposite holds. As a consequence of this, and given that the equilibrium output levels are decreasing in $k$, we can state the following.
Remark 9 For relatively low and relatively high values of $z$, firms choose a less polluting technology (lower $k$) but produce more in the absence of the environmentalists than in their presence.

For intermediate values of $z$, firms choose a more polluting technology (higher $k$) but produce less in the absence of the environmentalists than in their presence.

Proof. From remark 8, we know that the equilibrium output level is higher without the greens than with the greens for a given $k$. Further, from remarks 1 and 4 we know that the equilibrium level of output is increasing in $k$ in both cases. From remark 7 we know that firms choose less (more) polluting technologies when the environmentalists are present than when they are absent for intermediate values (low and high) of $z$. The rest of the remark follows. QED.

The last result does not mean that the total level of emissions would actually increase if environmentalists who are characterised by very low or very high degrees of impure altruism participated in the ETS. In fact, remark 9 emphasizes the existence of a trade-off between the technology choice and also the level of output. Higher degrees of impure altruism can actually induce firms to adopt worse technologies but could also lead to lower output levels. In fact, it would be necessary to evaluate the interaction between these two effects in order to assess which of the two is stronger.

6 Conclusions

In this paper we examine the participation of environmental groups in the Emissions Trading System (ETS) and its effects on firms’ technological choices. We examined the case where there are two firms in the tradable permits market which are acting as duopsonists in the product market and can choose their manufacturing technologies among a continuum of technologies which differ in their degree of environmental friendliness and their set-up
costs. In the spirit of Andreoni (1989, 1990), we consider that the environmentalists are impurely altruistic, that is, they do not only decide on the number of permits to withdraw based on traditional social welfare evaluation, but also take into account the increase in satisfaction they obtain from withdrawing permits.

We show that the environmentalists’ participation in the ETS can induce firms to choose a "greener" technology. This requires that the environmental group is characterized by intermediate degrees of impure altruism. Hence allowing the environmentalists to participation in the ETS can be used as a policy tool to accelerate the firms’ technological choice.

However, for very low or very high degrees of impure altruism the presence of the environmental group in the ETS could actually induce the firms to adopt a more polluting (non-green) technology. This does not imply that the total level of emissions would actually increase. In fact, two issues must be considered: the technology choice and also the level of output. Higher degrees of impure altruism can actually induce firms to adopt worse technologies but also could lead to lower output levels. In fact, the interaction between these two effects could lead to higher emissions levels for high and low degrees of impure altruism only under some specific conditions.

The work presented in this draft is still in progress. The reader might appreciate that the comparative statistics reported in section 5 have some limitations. In particular, the quantification of the two effects of the participation of the environmentalists (technology choice and output level) would be necessary to evaluate their impact on emission levels. This is one of the next objectives of our research, which we aim at completing in the upcoming months. Further, it is important to mention that in order to assess whether the environmentalists’ participation is beneficial for the society in broader terms (that is not only accounting for technology choices and level of emissions but also for the effects of their participation on the welfare of consumers and producers), an analysis of total surplus should be conducted.
7 References


Figure 1: Firms’ technology choice if the greens are not present in the ETS.
Figures 2.a.-2.d: Firms’ technology choice in the presence of the greens in the ETS

Figure 2.a: $a=1, \gamma=1$

Figure 2.b: $\gamma=1, a=1.5$
Figure 2.c: $\gamma = 1.5$, $a = 1$

Figure 2.d: $\gamma = 1.5$, $a = 1.5$