Heterogeneous National Allocation Plans in the EU Emission Trading Scheme under Imperfectly Competitive Markets

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Abstract

This paper extends a model by Ehrhart et al (2008) which examines duopoly under the EU Emission Trading Scheme, analyzing the effect of emissions permit price changes on firm profits. While their model assumes no initial allocation of permits to firms, the extension presented here incorporates heterogeneity in national allocation plans of pollution permits into the analysis. We find that, unlike Ehrhart et al, there are certain circumstances where a permit price increase will unambiguously lead to a rise in profit due to the initial allocation of permits. Because national allocation plans differ across member nations in the EU, these differing allocations have the potential to advantage some firms in the EU if they receive more permits than other firms. In addition, while Ehrhart et al (2008) state that at some point there may be an incentive to lobby for a lower allocation of permits, in this extension we find that while that incentive may exist, there also may be an incentive to lobby for more permits.

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1 Introduction

Climate change instruments historically have been dominated by the use of command-and-control methods such as quotas on pollutants, or environmental taxes. To a limited extent market-based instruments have also been used, notably with early starts in the United States in sulfur trading. However, the largest scale use of these market instruments is currently in operation in the European Union Emission Trading Scheme (EU ETS). This scheme, which all members of the European Union agree to abide by, allows for the trading of permits for pollution among member firms across the 27-nation bloc in accordance with their Kyoto Protocol-required reductions. The goal of the ETS was to allow a large degree of flexibility and control of carbon emissions, with direct control over quantity, rather than the price of pollution. These aims have seen varying degrees of success. While the EU has managed to create the market and provide for a given amount of pollution, there have been several problems that have plagued the system. These include the disharmonious nature of National Allocation Plans, time constraints, information asymmetries, all contributing to the price collapses that were seen in 2006. In this paper I will explore the institutional structure of the EU ETS including the concept of a national allocation plan (NAP). Examining the effect of the NAPs on the "over-allocation" of permits, we extend a model presented by Ehrhart et al (2008) which analyzes the implication of the ETS for tacit collusion in the context of a duopoly. The goal of this paper is to provide a possible explanation for the hetergeneity observed across national governments in creating their NAPs, and the resulting "over-allocation" of permits in phase I of the EU ETS.

As the current Obama Administration has expressed interest in climate change mitigation efforts, emissions trading (cap and trade) has been at the forefront of policy options that might be used to combat greenhouse gas emissions and climate change in the U.S. This paper, while extending a model designed for the EU, could easily have applications to the U.S. The the federal, decentralized nature of government in the U.S., with state and local governments having jurisdiction over several aspects of environmental policy, can be compared to the decentralized structure of the EU between the EU Commission and member nations.

2 Theory of Pollution Taxation and the Creation of the EU ETS

Pollution Taxation to Emissions Trading Many governments have historically opted for a taxation scheme in order to regulate polluting emissions. These have been implemented in all areas of Europe, as in the case of taxes for nitrous oxides that affect the power sectors in Sweden and France (Ecotec 2001), or water pollution taxes or pesticide taxes. Theoretically, implementing an environmental tax that is structured as a Pigouvian tax will result in an efficient outcome that both correctly prices the externality of polluting emissions

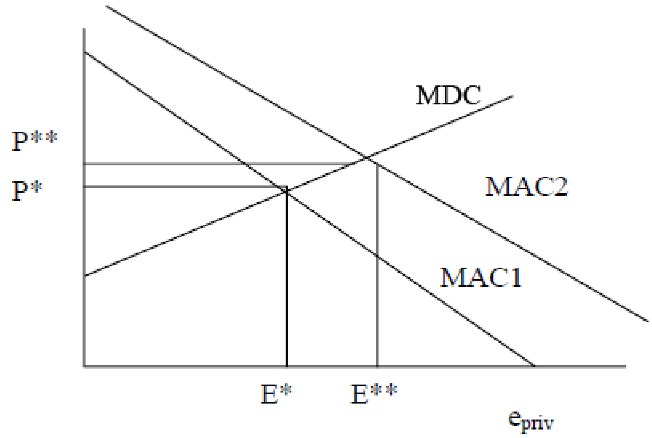


Figure 1

and achieves the necessary amount of pollution abatement. Unfortunately, in practice, this is near impossible due to information asymmetries. Take the example in figure 1 (Neumeyer 2007) which considers one marginal damage curve (MDC) for society and an aggregated marginal abatement cost (MAC) curve (MAC1).

While the true MAC curve is MAC1, this is not known to the government which views MAC2 as the relevant societal MAC curve due to information asymmetries between the government and the firms. If tax policy is incorrectly based on MAC2, the resulting price and quantity of emissions given respectively by P** and E** will be inefficient. Under conditions of perfect information however, the efficient price and quantity of emissions, given by P* and E* respectively, would be achieved. Furthermore, changes in technology and economic climate may change emissions levels while firms face a constant price for polluting rather than quantity. The goal of environmental taxes is to reduce pollution and they are able to keep pollution (emission) prices stable, however they cannot guarantee that the total amount of pollution that is emitted is constant.

The answer to this latter problem is a system of tradeable permits, which rather than taxing pollution, confers a right to pollute at a market-determined cost. This allows governments to effectively know how much is being polluted at all times rather than estimating with data from marginal abatement cost and marginal damage cost curves. This type of market-based pollution abatement mechanism is far from the norm, but has been used more and more recently in programs such as the US sulfur trading program.

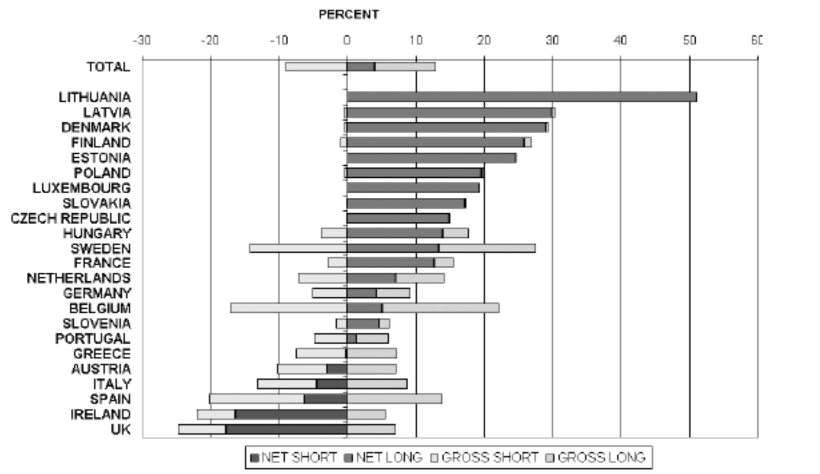
As a result of US demands that any climate change agreement include options to abate through emissions permit schemes, the Kyoto Protocol left open the door to a wide range of pollution abatement mechanisms. The EU decided, under the agreement, to create the European Union Emission Trading Scheme in 2003 (Europa 2009) as a way to effectively use a market instrument across the 27 nation bloc.

The EU Emission Trading Scheme In order to create such an emissions permit market, certain elements needed to be managed such as the amount of permits that were in the market, how they would be allocated, and how the market would work. In the EU, The allocations are distributed in a semi-decentralized manner.

Under the Kyoto Protocol, each country is required to commit to achieving and limiting its greenhouse gas emissions to a specific amount determined in relation to their 1990 level of greenhouse gas emissions. For some countries this may mean a decrease in greenhouse gas emissions (as for The US, UK, France and much of Western Europe), while for other countries this may imply an increase in greenhouse gas emissions (Greece)(UNFCCC) . The EU opted to accept all changes laid out in the Kyoto protocol and create an umbrella cap for the entire European Union (Kruger et al. 2007). Then, once the aggregate amount of emissions for the supranational bloc was determined, the EU Commission determines an individual target for each member state (Kruger et al. 2007). Given this target level of emissions, each member state is to submit a National Allocation Plan (NAP) to the central EU governing body outlining how allocations will be distributed among sectors (industries) and installations (factories, plants, etc). This includes descriptions of national strategies such as the use of auctioning and banking (the storing of unused permits in the present for use in the future) among other issues.

The fact remains then that the NAPs play a very important role in the EU ETS. At the same time, these national allocation plans can be problematic as they often are inequitable and ad hoc. A perfect example is the case of auctioning. In the first phase of the EU ETS (2005-2007)(Europa 2005), firms were permitted to auction a maximum of 5% of allowances. While only Denmark decided to use the full 5% with three other nations opting to auction at least part of their allowances (Ellerman and Buchner 2007), most other countries distributed their permits through other means. This may have placed Danish firms at a disadvantage relative to other EU firms as they possibly incurred the cost of paying for permits through an auction while other nations solely distributed their permits to their industries through grandfathering. Furthermore, because emissions allowances are given out by national governments, nation-specific rules are set regarding how allowances are to be treated. In Germany for instance, firms are allowed to keep allowances when moving to a new factory. On the other hand Finland and Spain do not permit the transfer of allowances, and if an installation does decide to close, the allowances given by the respective governments will be returned to the governments (Ahman et al. 2005). As will be discussed, heterogeneities create an uneven, albeit integrated market, with the possibilities of huge economic inefficiencies. For instance, in the case of Spain and Finland, the fact that allowances cannot be transferred (between installations under the same firm) incentivizes keeping old, inefficient plants running while the German proposal takes advantage of advances in technology to allow firms to change installations, keep allowances and possibly sell remaining allowances as a way to increase profits.

While the examples above highlight small inequities in NAPs, they describe



Source: Community Independent Transaction Log (2006) and Kettner et al. (2006) in Ellerman and Buchner (2007).

Figure 2

larger problems with NAPs, noticably the large differences in initial allocation of permits. The UK was allocated permits in a position that was net short for the country while nations such as Lithuania were allocated permits net long (Ellerman and Buchner 2007) as seen in figure 2.

This in turn led to purchases of permits by UK firms and sales by Lithuanian firms, advantaging Lithuanian firms and disadvantaging those in the UK. As will be shown later, these unequal distributions can permit a firm in one country to make a profit on a rising permit price while firms in the same industry in other nations may actually lose money.

Furthermore, divergences in the design and implementation of the EU ETS across member nations has implications for industrial policy, and raises the possibility of strategic interactions amongst firms competing in the regional market under conditions of imperfect competition. The goal of this paper is to analyze the effect of asymmetries in NAPs for emissions permits in the contect of a duopoly, where each rival firm dominates its own national market. In the following section we provide a brief literature review. The basic model presented by Ehrhart et al (2008) is described in section 4 along with the extension and analysis developed in this paper. Section 5 concludes with a brief summary.

3 Literature Review

The model in this paper is an extension of the one presented by Ehrhart et al (2008). In the first model of collusion that they consider in their paper, they examine at two duopolists who are price setters in the production of a homogeneous good, and who are price takers in the emissions permit market that is part of the EU ETS. In the game that Ehrhart et al (2008) model, in the first stage, firms decide on their output and then decide on their abatement (and inherently their pollution) levels in the second stage. What they find, interestingly is that under certain conditions, the exogenous rise in the price of a permit will actually increase the profits of a firm. Although the higher price will mean a higher cost to purchase permits, the firm may actually end up curtailing output (and hence increasing the price of the good) to such a degree that the increased revenue from producing this homogeneous good x actually surpasses the costs of the more expensive permits. Hence, they conclude that firms are able to collude tacitly in the presence of the exogenous permit price trading scheme (by both restricting output and raising the price). This has consequences of decreasing consumer welfare, higher profits for the industry and dead weight losses associated with the lower output. Their model assumes no initial allocation of permits and hence no differences across the NAPs in the application of permits across national lines. However, we extend their model to include such divergences across countries issuing number of pollution (emissions) permits or allowances.

Ellerman and Buchner (2006) analyze whether the sharp drop in permit prices in 2006 was a result of abatement or because national governments were overzealous in their initial allocation of permits and in fact over-allocated permits. Their results show that, under certain assumptions, there was over-allocation of permits. Although, this conclusion may not seem immediately relevant to the model presented above, the result of my thesis is very consistent with these results, namely, there may exist an incentive for national governments to over-allocate permits to firms. Indeed, Ellerman and Buchner (2006) argue that there is a probability that the over-allocation was intentional and that it clearly has repercussions on the equity of permit distribution in the EU.

Kruger et al (2007) also analyze the heterogeneity in national allocation plans. They question the desirability or optimality of issuing permits freely from national governments, rather than directly by the EU Commission. However, owing to political sensitivities, they concede that this method of permit allocation may have been the only alternative in order to receive approval from all member states. Despite this, though, they state that “the existing perception that some countries have adopted more aggressive targets in their NAPs, has made some member states question the fairness of NAPs” (Kruger et al, 2007, p. 129). As the heterogeneity between national allocation plans is introduced later in this paper, we will see that indeed discrepancies in NAPs is a major consideration and, under certain circumstances, firms may lobby for lower or higher allocations of permits.

Finally, Ellerman and Buchner (2006) also confirm some of the conclusions reached by Ehrhart et al. They point to the fact that much of the shortfall in allocated permits occured in the power-generating sector of the EU. This is consistent with the finding in Ehrhart et al that this sector is one that stands to benefit from higher permit prices and hence would be likely to lobby for lower allocation of permits. Betz and Sato (2006) and Ellerman and Buchner (2007) also confirm this.

4 The Model

Under the European Union ETS, firms in the 27-nation bloc have been forced to purchase permits in relation to the amount of pollution that they create and emit. However, one notable trait of the program has been that nations each distribute permits to their respective industries which has led to very unequal distribution across nations. This paper builds on the study by Ehrhart et al (2008) in which they construct a model showing that under certain conditions, the presence of the EU ETS actually allows firms in an oligopolistic market to restrict output and raise prices. This increases producer welfare while decreasing consumer welfare. However, this collusion that occurs is tacit and not the result of negotiations between firms. Their model does not take into account the initial allocation of permits to firms. Below we explore what happens to firms' profits and output when national allocation plans (NAPs) differ across nations and how this affects oligopolistic tacit collusion.

The model that Ehrhart et al (2008) use is elaborated upon here. I use their equations and explain them in slightly more detail than in their paper to facilitate understanding. In addition, I will use a simplifying assumption that firms in this model are Cournot-Nash duopolists.

They consider two identical firms in a duopoly that each produce a homogeneous good x_i with $x_i \in \mathbb{R}_+$, $i \in \{1, 2\}$. Market demand is given by $P(X) = P(x_1 + x_2)$ with $P_X < 0$ and $P_{XX} = 0$ which describes a typical straight line downward-sloping demand curve. Emissions for each firm are denoted by e_i and the price for a permit on the carbon market is p. Each firm treats this permit price p as fixed. Each firm has a cost function $C(x_i, e_i)$ with the following properties:

$$C_{e_i}(x_i, e_i) = \frac{\partial C(x_i, e_i)}{\partial e_i} < 0, \qquad C_{e_i e_i}(x_i, e_i) = \frac{\partial^2 C(x_i, e_i)}{\partial e_i^2} > 0 \tag{1}$$

$$C_{x_i e_i}(x_i, e_i) = \frac{\partial^2 C(x_i, e_i)}{\partial x_i \partial e_i} < 0$$

This reflects the fact that as the levels of emissions increase the cost to the firm decrease because less abatement technology is used. The convexity of this also illustrates that the least costly methods of abatement are used first. Finally, the third equation shows that as emissions decrease, the next unit of output is more costly to produce (as a result of using more expensive abatement technology and procedures).

Modeling the two stage game Ehrhart et al use a two stage game, the first stage having a firm fix a level of output and the second stage having that firm determine the optimal level of pollution (or abatement activities, depending on your perspective) The game is solved through backwards induction. We first solve for the second stage optimal level of pollution e_i^* and then we are able to make a decision on output in the first stage of the game.

Total Cost function The total cost to a firm can be thought of as the cost of producing a certain amount x_i while polluting a certain amount e_i (or alternatively while abating pollution from full pollution levels to e_i), plus the direct cost that the firm has to incur for the permits to pollute e_i. Thus, the firm's total cost function as represented in Ehrhart et al (2008) can be expressed as

$$TC(x_i, e_i) = C(x_i, e_i) + p \cdot e_i \tag{2}$$

where p is the price of a permit to emit 1 unit of pollution.

We introduce θ_i as the initial allocation of permits to firm i and rewrite the total cost function as (3):

$$TC(x_i, e_i, \theta_i) = C(x_i, e_i) + p \cdot (e_i - \theta_i) \tag{3}$$

As in Ehrhart et al (2008), solving for the second stage of the game (by backwards induction) we get:

$$min_{e_i} TC(x_i, e_i, \theta_i) \quad s.t. \quad e_i \geq 0 \tag{4}$$

$$\frac{\partial C(x_i, e_i^*)}{\partial e_i} + p = 0 \tag{5}$$

This can equivalently be written as

$$C_{e_i}(x_i, e_i^*) + p = 0$$

which is the marginal cost of pollution.
This function is in the form of an implicit function. That is, in this case we see that the optimal level of pollution, e_i^* is a function of output x_i as well as p, the price of a permit to emit one unit of emissions.

Now, because we have an implicit function we can analyze the way that the optimal amount of pollution changes as both output, x_i, and the price of permits, p, change [1].

$$\frac{\partial e_i^*(x_i, p)}{\partial x_i} = -\frac{C_{e_i x_i}(x_i, e_i^*)}{C_{e_i e_i}(x_i, e_i^*)} > 0, \qquad \frac{\partial e_i^*(x_i, p)}{\partial p} = -\frac{1}{C_{e_i e_i}(x_i, e_i^*)} < 0$$

As in Ehrhart et al (2008), we now have established that the optimal level of pollution, e_i^* increases as output increases and it decreases as the price of a permit goes up. Intuitively this makes sense. Adding another unit of output

[1] The use of the implicit function in this instance is presented in the appendix (6.1)

for a firm will require more resources to be used and hence more pollution will be produced, given properties of the cost function. As the price of a permit goes up, a firm that was previously polluting a fixed amount $\bar{e}$ will reduce its pollution. This is because at $\bar{e}$ a firm elected to abate until the level of pollution was equalized with permit price p. When the price of a permit rises, the efficient level of pollution falls.

Defining the cost-minimal level of emissions in (4) and (5) allows us now to have a cost minimized total cost function given by $TC^*(x_i, e^*(x_i, p), \theta_i)$

By applying the envelope theorem (as in Ehrhart et al) to this we obtain the following results[2]:

$$\frac{\partial TC^*}{\partial p} = e_i^* - \theta_i, \frac{\partial TC^*}{\partial x_i} = C_{x_i}(x_i, e_i^*)$$
$$\frac{\partial^2 TC^*}{\partial x_i^2} = C_{x_i x_i}(x_i, e_i^*) - \frac{C_{x_i e_i}(x_i, e_i^*)^2}{C_{e_i e_i}(x_i, e_i^*)} \tag{6}$$
$$\frac{\partial^2 TC^*}{\partial x_i \partial p} = -\frac{C_{x_i e_i}(x_i, e_i^*)}{C_{e_i e_i}(x_i, e_i^*)} > 0$$

One noticeable difference between this paper and that of Ehrhart et al. is the sign of $\frac{\partial TC^*}{\partial p}$. In their version, this term is necessarily ≥ 0 because it reduces to e_i^*. However, because this paper allows for a firm to have more permits than emissions, this term could, in theory, be negative. In fact this is not all that far-fetched as Ellerman and Buchner (2006) point out. They illustrate that many countries in the EU had firms that in fact were net long [3] in terms of permits (as in figure 2). Here, it is also important to note that Ehrhart et al provide illustrations of the electricity sector and the properties of their total cost functions which become important later:

$$\frac{\partial TC^*}{\partial x_i} = C_{x_i}(x_i, e_i^*) > 0 \qquad \frac{\partial^2 TC^*}{\partial x_i^2} < 0$$

The First Stage of the Game Because we are solving this problem through backwards induction, now that the second stage of the game has been completed and solved for we move on to the first stage of the game in which a firm maximizes its profit after defining of its cost-minimal amount of pollution (e_i^* in the second stage). The profit function for firm i is represented as:

$$\Pi_i(x_i^*, x_{-i}^*, e_i^*, p, \theta_i) = P(x_i + x_{-i}) \cdot x_i - TC(x_i, e_i^*(x_i, p), \theta_i) \tag{7}$$

Thus when looking at the firm's output decision, solving the first order condition with respect to output, in a Cournot-Nash equilibrium yields:

$$P(x_i + x\_i) + P_X(x_i + x_{-i}) \cdot x_i - TC_{x_i}^*(x_i, p) = 0 \tag{8}$$

[2]Only $\frac{\partial TC^*}{\partial p}$ differs from Ehrhart et al's calculations

[3]Had more permits than emissions

In a Cournot-Nash setting $P_X = P_{x_i}$ given that each firm is myopic and assumes that when it makes its output decision, this has no bearing on the other firm's behavior. This difference in notation has no effect on our results.

By examining the second order condition, (as in Ehrhart et al) we get:

$$2 \cdot P_X(x_i + x_{-i}) - TC^*_{x_i x_i}(x_i, p) < 0 \tag{9}$$

Equation 8 is the best response function for each firm. Even though the initial allocation of permits may be different between firms, the best response function remains the same as in Ehrhart et al.'s model. This is because the only place where θ_i appears is in the total cost (TC) term. However, when this term (TC) is differentiated with respect to x_i the θ_i term disappears. Thus, we are left with the symmetric best response functions for both firms. Thus when $i \in \{1, 2\}$ we have $x_1^* = x_2^* = x^*$.

The heart of the matter is this: When the permit price increases, this will cause the firm's total cost to rise. In addition though it will cause output to fall. Thus by using the implicit function theorem we are able to look at the effect that price of permits, p, has on the level of output for a given firm. These two effects oppose each other. On one hand, more expensive permits mean higher costs, but they may imply higher revenue for the firm due to higher product price (this higher product price is the result of output restriction given by the implicit function below). The result of the implicit relationship described above is [4]:

$$\frac{dx^*}{dp} = \frac{TC^*_{x_i,p}(x_i, p)}{3 \cdot P_X(2x^*) - TC^*_{x_i x_i}(x_i, p)} \tag{10}$$

Given equations (6), (9) and the fact that $P_X < 0$, we know that $\frac{\partial x^*}{\partial p} < 0$.

In order to see how exogenous changes in p affect profits for a given firm, we differentiate the profit function with respect to the price of a permit p

$$\frac{d\Pi}{dp} = P_X(2x^*) \cdot 2\frac{dx^*}{dp} \cdot x^* + P(2x^*) \cdot \frac{dx^*}{dp} - TC_x(x^*, p, \theta_i) \cdot \frac{dx^*}{dp} - TC_p(x^*, p, \theta_i)$$

$$\frac{d\Pi}{dp} = P_X(2x^*) \cdot x^* \frac{dx^*}{dp} + \frac{dx^*}{dp}(P_X(2x^*) \cdot x^* + P(2x^*) - TC_x(x^*, p, \theta_i)) - TC_p(x^*, p, \theta_i)$$

Combined with equation 8 yields:

$$\frac{d\Pi}{dp} = x^* \cdot P_X(2x^*)\frac{dx^*}{dp} - TC_p(x^*, p, \theta_i) \tag{11}$$

Which corresponds to equation (18) in Ehrhart et Al.

Thus (10) and (11) lead to:

$$\frac{d\Pi}{dp} = \frac{x^* \cdot P_X(2x^*)}{3 \cdot P_X(2x^*) - TC^*_{x_i x_i}(x_i, p, \theta_i)} TC^*_{x_i,p}(x_i, p, \theta_i) - TC_p(x^*, p, \theta_i)$$

[4]Derivation can be found in the appendix (6.2)

Substituting from (6) we can now say that $\frac{d\Pi}{dp}$ is positive iff

$$\frac{x^* \cdot P_X(2x^*)}{3 \cdot P_X(2x^*) - TC^*_{x_i x_i}(x^*, p, \theta_i)}(e^*_{i x_i}(x^*, p) - \theta_{i x_i}) - e^*_i(x^*, p) + \theta_i > 0$$

after terms = 0 are removed:

$$\frac{x^* \cdot P_X(2x^*)}{3 \cdot P_X(2x^*) - TC^*_{x_i x_i}(x^*, p, \theta_i)} e^*_{i x_i}(x^*, p) - e^*_i(x^*, p) + \theta_i > 0$$

Now multiplying this by $\frac{1}{e^*}$ and defining the elasticity $\epsilon_x(f(x)) = \frac{\partial f(x)}{\partial x} \cdot \frac{x}{f(x)}$ as in Ehrhart et al (2008), we then have

$$\frac{P_X(2x^*)}{3 \cdot P_X(2x^*) - TC^*_{x_i x_i}(x^*, p, \theta_i)} \epsilon_{x_i}(e^*_i(x^*, p)) - 1 + \frac{\theta_i}{e^*_i} > 0 \tag{12}$$

or equivalently:

$$\frac{P_X(2x^*)}{3 \cdot P_X(2x^*) - TC^*_{x_i x_i}(x^*, p, \theta_i)} \epsilon_{x_i}(e^*_i(x^*, p)) + \frac{\theta_i}{e^*_i} > 1 \tag{13}$$

The term below shall be denoted as B:

$$\frac{P_X(2x^*)}{3 \cdot P_X(2x^*) - TC^*_{x_i x_i}(x^*, p, \theta_i)}$$

In Ehrhart et al, B is defined as:

$$\frac{(1-\delta) \cdot P_X(2x^*)}{(3+\delta) \cdot P_X(2x^*) - TC^*_{x_i x_i}(x^*, p, \theta_i)}$$

which we will call $B_{Ehrhart}$

They prove that for a parameter $\delta \in [-1, 1)$, $B_{Ehrhart} \in (0, 1)$. This is shown below.

$$\lim_{TC^*_{x_i x_i}(x^*, p) \to 2(1+\delta) P_X(2x^*)} \frac{(1-\delta) \cdot P_X(2x^*)}{(3+\delta) \cdot P_X(2x^*) - TC^*_{x_i x_i}(x^*, p)} = 1$$

$$\lim_{TC^*_{x_i x_i}(x^*, p) \to \infty} \frac{(1-\delta) \cdot P_X(2x^*)}{(3+\delta) \cdot P_X(2x^*) - TC^*_{x_i x_i}(x^*, p)} = 0$$

In the case that we have outlined in this paper, that is a Cournot-Nash case, $\delta = 0$. When $\delta = 0$ we can be sure that $B = B_{Ehrhart}$. When $\delta = 0$, we know the following:

$$B_{Ehrhart} = \frac{P_X(2x^*)}{3 \cdot P_X(2x^*) - TC^*_{x_i x_i}(x^*, p)}$$

The B outlined in this paper is:

$$B = \frac{P_X(2x^*)}{3 \cdot P_X(2x^*) - TC^*_{x_i x_i}(x^*, p, \theta_i)}$$

Despite the fact that the TC term in our modified model is in terms of three variables (including θ_i), when our TC term is differentiated twice with respect to x_i, any terms having θ_i disappear. Thus $B_{Ehrhart} = B$

Thus we are certain that $B \in (0, 1)$. The elasticity measures the percent change in emissions with a given percent change in output and is always positive [5].

We can show that the profit of a firm increases with an increasing permit price only if the following holds $B \cdot \epsilon_{x_i}(e_i^*(x^*, p)) + \frac{\theta_i}{e_i^*} > 1$ which we have shown through equation 13 as well as our definition of B and the elasticity.

This situation is significantly different from Ehrhart et Al by the last term $\frac{\theta_i}{e_i^*}$. In the case of Ehrhart et al, they argue that because $B \in (0, 1)$, the elasticity must always be > 1 in order for the condition to hold which would allow higher permit prices to yield an increasing profit. However, with this model, this is no longer the case. It is clear that the $\frac{\theta_i}{e_i^*}$ term helps to mitigate a low elasticity of emissions or a low B. That is, if $B \cdot \epsilon_{x_i}(e_i^*(x^*, p)) \leq 1$ in Ehrhart's model, profit will not rise as permit price rises. However in this extension it is permissible for $B \cdot \epsilon_{x_i}(e_i^*(x^*, p)) \leq 1$ and have profits still rise as permit price rises so long as $\frac{\theta_i}{e_i^*} > 0$ such that $B \cdot \epsilon_{x_i}(e_i^*(x^*, p)) + \frac{\theta_i}{e_i^*} > 1$. This $\frac{\theta_i}{e_i^*}$ may also allow one firm in the EU of a good x_i to become a high-cost producer and another to become a low-cost producer.

If both have two identical firms (identical output, emissions, cost functions,etc) in two different countries with the following true:

$$B \cdot \epsilon_{x_i}(e_i^*(x^*, p)) = .5$$

but one has $\frac{\theta_i}{e_i^*} = .75$ and the other has $\frac{\theta_i}{e_i^*} = .25$, the one with the higher proportion of permits to emissions will see profits rise as the price of a permit goes up while the other will see profits fall as permit price rises. In a realistic situation, as we have outlined before, if one firm is in a country where emissions are allowed to rise and another firm is in a country that must cut back its emissions, this scenario is likely and demonstrates that some firms may lobby for fewer permits while others for more. The firm in one country may lobby for fewer permits to its industry across the EU on some environmental grounds knowing full well, because it is in a country that is allowed to increase emissions that $\frac{\theta_i}{e_i^*}$ will always be high. By lobbying to the EU commission that its industry is polluting, it may lower the permit allocation to other firms across the EU, thus securing its place as a low cost producer and ensuring a profit increase as permit prices rise. At the same time, the other firm will lobby in the opposite

[5]Because $\frac{\partial e_i^*}{\partial x} > 0$ and $x_i \geq 0$ and $e_i^* \geq 0$

direction hoping to get $\frac{\theta_i}{e_i^*}$ high enough that any permit price rise will also benefit it.

One notable situation is when $\theta_i > e_i^*$. In this case, the firm will always see its profits increase with higher permit prices no matter what the elasticity is or what B is. As we saw in Phase I of the EU ETS, this is a situation that must be accounted for. Because there were so many instances of over-allocation of permits in the EU ETS, it shows that perhaps governments had incentives to allocate far more permits than were necessary to each firm. Going back to the Buchner and Ellerman (2006) paper questioning whether permits were over-allocated or if there was abatement, this extension of Ehrhart et al helps to defend the hypothesis that in many cases, permits were actually over-allocated intentionally in the hope of not disadvantaging any domestic industry relative to other EU companies operating in the same market.

5 Conclusion

In this paper we extend the model presented by Ehrhart et al by incorporating initial allocation of pollution permits which differ across imperfectly competitive (duopolists) national firms, located in different countries. Ehrhart et al find that under certain conditions, firms in a duopoly may benefit (higher profits) from a higher permit price and hence they may use methods such as lobbying for fewer permits to be issued in order to ensure a scarcity of permits (and hence a higher price). However, when initial allocations of emission permits are allowed to vary across firms and nations (within an industry), even among otherwise identical rivals, some firms may benefit from an emissions permit price increase, while a competitor located in another EU member country may stand to lose from such a permit price increase.

In this case, rather than lobbying for fewer permits, we may also see businesses lobbying for more permits. If $B \cdot \epsilon_{x_i}(e_i^*(x^*, p)) \leq 1$ we may see firms lobbying for more permits in hopes that the $\frac{\theta_i}{e_i^*}$ is high enough so that $B \cdot \epsilon_{x_i}(e_i^*(x^*, p)) + \frac{\theta_i}{e_i^*} > 1$. This extra parameter that we added in our model may explain why there was such a large abundance of permits in 2006. If nations wanted to make sure that their industries were competitive on the EU market, they would have wanted to make sure that $\frac{\theta_i}{e_i^*} > 1$. This way, in an oligopolistic market, the government would be sure that the profits of a particular domestic firm would rise.

6 Appendix

6.1 Using the Implicit Function Theorem to find $\frac{\partial e_i^*}{\partial x_i}$ and $\frac{\partial e_i^*}{\partial p}$

Consider the equation in (5). This can be rephrased in the following manner:

$$F(e_i^*, x_i, p) = C_{e_i}(x_i, e_i^*) + p = 0 \tag{14}$$

To find how the efficient level of pollution e_i^* is affected by the output x_i we need to examine $\frac{\partial e_i^*}{\partial x_i}$
This results in

$$\frac{\partial e_i^*(x_i, p)}{\partial x_i} = -\frac{F_{x_i}(e_i^*, x_i, p)}{F_{e_i}(e_i^*, x_i, p)} = -\frac{C_{e_i x_i}(x_i, e_i^*)}{C_{e_i e_i}(x_i, e_i^*)} > 0 \tag{15}$$

Similarly we can examine the effect that price has on the optimal level of pollution through the following set of equations

$$\frac{\partial e_i^*(x_i, p)}{\partial p} = -\frac{F_p(e_i^*, x_i, p)}{F_{x_i}(e_i^*, x_i, p)} = -\frac{1}{C_{e_i e_i}(x_i, e_i^*)} < 0 \tag{16}$$

6.2 Using the implicit function theorem to find $\frac{dx^*}{dp}$

Let F be defined by the following (which is also equation 8):

$$F = P(x_i + x_-i) + P_X(x_i + x_-i) \cdot x_i - TC^*_{x_i}(x_i, p) = 0$$

Because we are dealing with symmetric firms we also can set $x_1 = x_2 = x^*$. In order to find $\frac{\partial x^*}{\partial p}$ we find $-\frac{F_p}{F_{x^*}}$. This yields the following:

$$F_p = -TC^*_{x_i,p}(x_i, p) \cdot 1 \tag{17}$$

$$F_{x^*} = 2 \cdot P_X(2x^*) + P_{XX}(2x^*) \cdot x^* + P_X(2x^*) - TC^*_{x_i x_i}(x_i, p) \tag{18}$$

However because the model stipulates that $P_{XX} = 0$ we end up with:

$$F_{x^*} = 3 \cdot P_X(2x^*) - TC^*_{x_i x_i}(x_i, p) \tag{19}$$

Thus in total we have:

$$\frac{\partial x^*}{\partial p} = -\frac{F_p}{F_{x^*}} = \frac{TC^*_{x_i,p}(x_i, p)}{3 \cdot P_X(2x^*) - TC^*_{x_i x_i}(x_i, p)} \tag{20}$$

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