The Allocation of Tradeable Emission Permits within Federal Systems (or Economic Unions) *

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May 24, 2006

*We are very much indebted to Stefano Alaimo for his contribution at earlier stages of this research. We also wish to thank Laura Castellucci, Stefano Gorini, Tim Hoffmann and Piercarlo Zanchettin for their comments, as well as seminar audience at the Universities of Cassino and Nottingham and partecipants at EAERE and SIEP in 2005.

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Abstract

This paper deals with the issue of whether the power of allocating tradeable emission permits within a federal system (or an economic union) should be centralized or delegated to the single states/nations. To this end, we develop a simple two stage game played by two governments and their respective industries producing a homogeneous output that is sold in a third country. We show that when emission permits are traded competitively at a federal (or economic union) level, a decentralized emission trading system (DETS) would result in a lower than optimal price of permits, as well as in an aggregate emission target which is larger than the socially optimal target that would arise under a centralized system (CETS). This result partly hinges on standard international externality considerations; on the other hand, we find a new "channel" through which decentralized permits distribution could lead to distortions: under a DETS, national governments play a Cournot game, and choose the amount of allowances to be distributed to domestic firms without accounting for the spillover such distribution generates on the other country *via* the price of allowances.

(**JEL numbers:** F18, Q50. **Keywords:** emissions trading, environmental dumping, environmental federalism)

1 Introduction

The most recent and important evidence of the growing attention that tradeable emission permits are receiving from environmental policy makers is definitely the implementation by the European Union of a trading system for Greenhouse Gases emissions as a step towards the achievement of the Kyoto targets (Directive 2003/87/CE). The EU Directive provides an example of decentralized emission trading system (DETS): under this regime permits are traded at the Union level, but each member state has a certain degree of freedom in specifying both the total amount of permits to be allocated within its boundaries and how this amount may be divided among the sectors subject to regulation, and among installations within each sector. In this paper we use a stylized theoretical model to compare a DETS with an alternative system setting the power of allocating the total amount of permits at a central (federal or economic union) level. We refer to such an alternative system as a centralized emission trading system (CETS)[1]. We show that the DETS would result in a lower than optimal price of permits, as well as in an aggregate emission target which is larger than the socially optimal target that would arise under the CETS. This result partly hinges on standard international externality considerations. However, another effect must be accounted for: in a DETS, when national shares in total emissions are large enough, then each government will be able to affect the equilibrium permits price; in this case, national governments play a Cournot game and choose the amount of allowances to be distributed to domestic firms without accounting for the spillover such distribution generates on other countries *via* the equilibrium price of permits.[2].

In broader terms, the degree of decentralization in environmental

[1]As an example of CETS we can think about the SO_2 trading system implemented in the US where a centralized regulatory agency controls at a federal level the allocation of all emission permits for all participating firms in all states.

[2]Pratlong [8] derives a similar result in a different setting where national firms act in oligopolistic product markets and trade their emission permits in perfectly competitive national markets.

policy is a crucial issue. One basic principle of fiscal federalism (the so called "principle of subsidiarity") claims that it would be better to decentralize public policies to the jurisdictional levels which is closer to the preferences of consumers and/or producers; nonetheless, environmental policy may represent an important exception and the principle of subsidiarity may be "*the subject of a widespread and fundamental challenge both at the theoretical and policy levels. The source of this challenge is the claim that interjurisdictional competition among decentralized levels of government introduces serious allocative distortions*" (Oates [7], p. 1134). One way such competition may take place is through the attempt of national (or regional) governments to relax environmental policy in order to secure to domestic firms competitive advantages in international markets. This issue is the subject of a number of papers dealing with "environmental dumping" in both international (as in Barrett [1] and Ulph [9]) and federal settings (Ulph [10] and [11]). Our modelling strategy follows the one adopted by that strand of literature but, unlike all the above papers, we *a)* consider emission trading instead of standards or taxes, *b)* focus on a problem of transboundary pollution (which is more suitable to illustrate the case of Greenhouse Gases emissions), and *c)* do not assume any imperfect competition in the output market (which is, in the above cited literature, a necessary condition for having national governments acting strategically). As a consequence, the source of distortion identified in this paper adds to the ones addressed in the received literature.

Other theoretical papers deal with questions which are closely related to the issue analyzed in this paper. Böhringer and Lange [2], for instance, show that the optimal design for allocating tradeable emission permits depends on whether the system is closed, that is a CETS regulated by a unique centralized agency, or open, that is a DETS where different regulatory agencies assign a fraction of the total number of allowances to be traded with outsider firms. The main focus of their paper, however, is on the most appropriate metrics for the allocation of allowances - namely lump sum allocation (that is not based on historical emissions/output) versus assignment rules which allocate permits proportionally to the emissions or production of the preceding periods. On the contrary, we evaluate the CETS and the DETS by comparing their aggregate emissions targets with the socially optimal one.

Our paper is also complementary to the work by Helm [6] who analyzes in a very similar setting the allocation of emission permits under two alternative regulatory regimes, namely with and without the possibility of trading permits. In his paper Helm finds that the possibility of trading may induce more pollution since the higher number of permits chosen by environmentally less concerned countries may offset the choices of the more concerned ones[3]. Nevertheless since he focuses on an international scenario where the allocation of emission permits *is chosen by interdependent yet sovereign states* (Helm [6], p.2738), his analysis does not allow for the case of a centralized authority (CETS).

To derive our results we use a two stage game played by two governments and their respective industries producing a homogeneous output that is sold in a third country. Governments move first and choose the amount of permits to be provided to firms operating within their borders. As already outlined, we consider two alternative institutional frameworks, namely a CETS, where the two governments act as a single entity, and a DETS, where they play a Cournot game, that is, each government chooses the amount of permits to be issued to the firm(s) located within its borders and takes other government's choices as given. In the second stage each firm observes the amount of permits that have been assigned to it and chooses the level of output and emissions. While the main other features of this model are presented in the next section, the rest of the paper is organized as follows: section 3 derives the conditions characterizing the optimal choices of the firms in the second stage of the game, section 4 analyzes how the two governments choose (jointly or separately) the amount of allowances to be issued to the firms and, finally, section 5 concludes.

[3]Boom and Dijkstra [3] expand the analysis of Helm [6]. By including boundary solutions they show that in some cases the results presented by Helm do not hold.

2 The structure of the model

We analyze a stylized model representing a Federal State - we could alternatively think about an Economic Union - formed by two countries (a domestic one, labelled as d, and a foreign one, labelled as f). In each country an identical (and large) number of firms produces a homogeneous output which is sold in a competitive output market located in a third country[4]. By normalizing to 1 the number of firms in each country, we deal with one "representative" firm in the domestic country (firm d) and one in the foreign country (firm f). Each firm's production q_i generates polluting emission e_i $(i = d, f)$. To keep matters as simple as possible, we assume that there is a one to one relationship among output and emissions and the only way to reduce emissions is by reducing output, i.e. $e_i = q_i$. Emissions cause *transboundary pollution*; the total environmental damage is given by $D(q_d + q_f)$, where, as it is standard, we assume that $\frac{\partial D}{\partial q_i} > 0$, $\frac{\partial^2 D}{\partial q_i^2} > 0$ and $\frac{\partial^2 D}{\partial q_i \partial q_j} > 0$ $(i, j = d, f)$[5].

The interactions among the two firms and the governments of the two countries are defined by the following two stage game. In the first stage, the two national governments, d and f, choose the amount of emission permits, $\overline{e}_d$ and $\overline{e}_f$, to be issued to each "representative" firm. We consider two alternative institutional frameworks, namely a CETS, where the two governments act as a single entity, and a DETS, where each government chooses the amount of permits to be issued to the firm(s) located within its borders and takes other government's choices as given. More specifically, under the CETS the two governments jointly choose the amount of $\overline{e}_d$ and $\overline{e}_f$ in order to maximize the difference between total profits and total environmental damages,

$$W = \Pi_d(\overline{e}_d, \overline{e}_f) + \Pi_f(\overline{e}_d, \overline{e}_f) - D(q_d(\overline{e}_d, \overline{e}_f) + q_f(\overline{e}_d, \overline{e}_f)). \qquad (1)$$

On the other hand, under the DETS, each government chooses its

[4]By this assumption we follow the standard environmental dumping literature and simplify the analysis by ruling out consumers' surplus.

[5]Emissions coming from the two countries are, therefore, implicitly assumed to be perfect substitutes in the environmental damage function.

emissions target taking the other government's choice as given and aiming at maximizing domestic firm's profits less the damage born by domestic citizens, which is simply assumed to be a fraction of total damages. Thereby, government d chooses $\overline{e}_d$ in order to maximize the following objective function:

$$W_d = \Pi_d\left(\overline{e}_d, \overline{e}_f\right) - \beta D\left(q_d\left(\overline{e}_d, \overline{e}_f\right) + q_f\left(\overline{e}_d, \overline{e}_f\right)\right), \tag{2}$$

while the foreign government chooses $\overline{e}_f$ in order to maximize

$$W_f = \Pi_f\left(\overline{e}_d, \overline{e}_f\right) - (1-\beta)\, D\left(q_d\left(\overline{e}_d, \overline{e}_f\right) + q_f\left(\overline{e}_d, \overline{e}_f\right)\right). \tag{3}$$

In the above functions, β and $(1-\beta)$ represent the fractions of the total damage $D(q_d + q_f)$ born by the citizens of the two countries ($\beta \in (0,1)$): such fractions may be determined, for example, by geographical and/or meteorological reasons.

Taking as given the values of $\overline{e}_d$ and $\overline{e}_f$, in the second stage the two "representative" firms choose their output (and emission) levels (q_d and q_f respectively) in order to maximize their profits, Π_d and Π_f. The profit of the "representative" firm operating in country i ($i = d, f$) is

$$\Pi_i = p_q q_i - c_i(q_i) - p_e(e_i - \overline{e}_i) \tag{4}$$

where $p_q, c_i(q_i)$ and p_e are the output price, production costs in country i and the permits price respectively. Costs are assumed to be increasing and convex in q_i. The last term of the profit function is the amount of money the firm spends (earns) if it is a net buyer (seller) of permits; finally, $e_i(= q_i)$ is the emission level of country i.

In the following two sections we solve this two stage game backward.

3 Stage 2: The firms

In this section we derive the conditions characterizing the optimal choices of the firms in the second stage of the game. A first straightforward result follows directly from the first order conditions of the firms' profit maximization.

Proposition 1. *The firms' optimal level of output (and emissions) decreases as the equilibrium price in the emission permits market increases.*

Proof. Assuming interior solutions, the first order conditions for the maximization of (4) are:

$$\frac{\partial \Pi_i}{\partial q_i} = p_q - \frac{\partial c_i(q_i)}{\partial q_i} - p_e = 0 \tag{5}$$

$(i = d, f)$[6]. Competitiveness in the output market implies that the output price is perceived by firms as a constant. Then, comparative statics leads to

$$-\frac{\partial^2 c(.)}{\partial q_i^2}\frac{dq_i}{dp_e} - 1 = 0$$

that is

$$\frac{\partial q_i}{\partial p_e} = -\frac{1}{\frac{\partial^2 c_i(.)}{\partial q_i^2}} < 0 \tag{6}$$

for all $i = d, f$. □

The result that emissions are decreasing in permits' price is quite reasonable. On the other hand, condition (5) simply requires that marginal benefits of production equal marginal "private" costs, where p_e may be either part of the marginal benefits, if the firm is a net seller of permits, or part of the marginal "private" costs, if it is a net buyer of permits.

The equilibrium price of permits is implicitly defined by the following market clearing condition[7]:

$$q_d + q_f = \overline{e}_d + \overline{e}_f. \tag{7}$$

From such condition we can derive the sign of the relationship between the equilibrium level of p_e and the initial endowments of permits

[6]Second order sufficient conditions for an optimum are clearly satisfied, as $\frac{\partial^2 \Pi}{\partial q_i^2} = -\frac{\partial^2 c_i(.)}{\partial q_i^2} < 0$.

[7]We limit our attention to the case of a strictly positive equilibrium permits price.

in the two countries. Differentiating (7) with respect to $\overline{e}_d$ and $\overline{e}_f$ respectively, and using (6) we get:

$$\frac{\partial p_e}{\partial \overline{e}_d} = \frac{\partial p_e}{\partial \overline{e}_f} = \frac{\partial p_e}{\partial e} = -\frac{1}{\frac{1}{\frac{\partial^2 c_d(.)}{\partial q_d^2}} + \frac{1}{\frac{\partial^2 c_f(.)}{\partial q_f^2}}} < 0. \tag{8}$$

where the assumption that production costs are increasing and convex in q_i guarantees the negativeness shown in (8), while $e = \overline{e}_d + \overline{e}_f$. From (6) and (8) we can further conclude, as it is reasonable, that $\frac{\partial q_i}{\partial \overline{e}_i} = \frac{\partial q_i}{\partial p_e}\frac{\partial p_e}{\partial \overline{e}_i} > 0$ and $\frac{\partial q_i}{\partial \overline{e}_j} = \frac{\partial q_i}{\partial p_e}\frac{\partial p_e}{\partial \overline{e}_j} > 0$.

Now we can study how maximum profits vary with the initial endowment of permits. To deal with this issue we have to consider two possible effects related to a change in the amount of emission permits issued by government(s). First of all there is a direct positive effect: getting more emission permits make firms better off as they can either sell more or buy less permits. We call this the "wealth effect". On the other hand, firms' profits are also indirectly affected by the levels of emission permits through the negative relationship between p_e and $\overline{e}_i$ $(i = d, f)$. This second effect, that we define as the "price effect", is positive (negative) only if the firm is a net buyer (seller) of permits. Therefore we can state and proof the following result:

Proposition 2. *Increasing the amount of emission permits allocated to the "representative" firm operating in country i makes the same firm better off*

- *always, when the firm itself is a net permits buyer*
- *only if the "wealth effect" dominates the "price effect" when the firm itself is a net seller.*

Increasing the amount of emission permits allocated to the "representative" firm operating in country j makes the firm operating in country i better off only if the same firm is a net permits buyer.

Proof. Differentiating Π_i w.r.t. $\overline{e}_i$ we get:

$$\frac{\partial \Pi_i}{\partial \overline{e}_i} = p_q \frac{\partial q_i}{\partial p_e}\frac{\partial p_e}{\partial \overline{e}_i} - \frac{\partial c}{\partial q_i}\frac{\partial q_i}{\partial p_e}\frac{\partial p_e}{\partial \overline{e}_i} - \frac{\partial p_e}{\partial \overline{e}_i} q_i + \frac{\partial p_e}{\partial \overline{e}_i}\overline{e}_i - \frac{\partial q_i}{\partial p_e}\frac{\partial p_e}{\partial \overline{e}_i} p^e + p^e$$

which can be rewritten as:

$$\frac{\partial \Pi_i}{\partial \overline{e}_i} = \left(p_q - \frac{\partial c}{\partial q_i} - p^e \right) \frac{\partial q_i}{\partial p_e} \frac{\partial p_e}{\partial \overline{e}_i} - \frac{\partial p_e}{\partial \overline{e}_i} q_i + \frac{\partial p_e}{\partial \overline{e}_i} \overline{e}_i + p^e$$

Finally, by using (5) we get:

$$\frac{\partial \Pi_i}{\partial \overline{e}_i} = p^e - \frac{\partial p_e}{\partial \overline{e}_i}(q_i - \overline{e}_i)$$

The first term on the right hand side is the "wealth effect" related to an increase in the initial endowment of permits, while the second is a "price effect", whose sign depends on the firm being net buyer or seller of permits. Differentiating Π_i w.r.t. $\overline{e}_j$ and following the same argument as for $\overline{e}_i$ we get:

$$\frac{\partial \Pi_i}{\partial \overline{e}_j} = -\frac{\partial p_e}{\partial \overline{e}_j}(q_i - \overline{e}_i)$$

In this case, of course, the wealth effect disappears. From the two partial derivatives it is clear that:

- $\frac{\partial \Pi_i}{\partial \overline{e}_i} > 0$ if $q_i > \overline{e}_i$, while if $q_i \leq \overline{e}_i$ then the sign of $\frac{\partial \Pi_i}{\partial \overline{e}_i}$ is ambiguous
- $\frac{\partial \Pi_i}{\partial \overline{e}_j} \geq 0$ if $q_i \geq \overline{e}_i$

□

4 Stage 1: The governments

In the first stage of the game the two governments choose (jointly or separately) the amount of emission allowances to be issued to the two "representative" firms, $\overline{e}_d$ and $\overline{e}_f$, taking into account how firms will react in the second stage. In so doing the two governments realize that the equilibrium price in the permits market can be influenced by their choice of $\overline{e}_i$ $(i = d, f)$. The aim of this section is, therefore, to assess how the amount of permits allocated in each country changes when moving from a centralized setting to a decentralized one. We start analyzing what happens when the two governments act as a single entity, maximizing (1):

Proposition 3. *Under the CETS, the aggregate emissions target is set by the two governments at its first best level.*

Proof. The FOCs from the welfare maximization problem under the CETS are[8]

$$\frac{\partial W}{\partial \overline{e}_d} = \frac{\partial \Pi_d}{\partial \overline{e}_d} + \frac{\partial \Pi_f}{\partial \overline{e}_d} - \frac{\partial D}{\partial q_d}\frac{\partial q_d}{\partial p_e}\frac{\partial p_e}{\partial \overline{e}_d} - \frac{\partial D}{\partial q_f}\frac{\partial q_f}{\partial p_e}\frac{\partial p_e}{\partial \overline{e}_d} = 0$$

$$\frac{\partial W}{\partial \overline{e}_f} = \frac{\partial \Pi_d}{\partial \overline{e}_f} + \frac{\partial \Pi_f}{\partial \overline{e}_f} - \frac{\partial D}{\partial q_d}\frac{\partial q_d}{\partial p_e}\frac{\partial p_e}{\partial \overline{e}_f} - \frac{\partial D}{\partial q_f}\frac{\partial q_f}{\partial p_e}\frac{\partial p_e}{\partial \overline{e}_f} = 0$$

As environmental damages only depend on the total amount of emissions, then $\frac{\partial D}{\partial q_d} = \frac{\partial D}{\partial q_f}$. Moreover, $\frac{\partial q_d}{\partial p_e}\frac{\partial p_e}{\partial \overline{e}_d} + \frac{\partial q_f}{\partial p_e}\frac{\partial p_e}{\partial \overline{e}_d} = \frac{\partial q_d}{\partial p_e}\frac{\partial p_e}{\partial \overline{e}_f} + \frac{\partial q_f}{\partial p_e}\frac{\partial p_e}{\partial \overline{e}_f} = 1$, so that we can rewrite the first order conditions for the centralized government as follows:

$$\frac{\partial W}{\partial \overline{e}_d} = p^e - \frac{\partial p_e}{\partial \overline{e}_d}(q_d - \overline{e}_d) - \frac{\partial p_e}{\partial \overline{e}_d}(q_f - \overline{e}_f) - \frac{\partial D}{\partial q_d} = 0 \tag{9}$$

and

$$\frac{\partial W}{\partial \overline{e}_f} = p^e - \frac{\partial p_e}{\partial \overline{e}_f}(q_f - \overline{e}_f) - \frac{\partial p_e}{\partial \overline{e}_f}(q_d - \overline{e}_d) - \frac{\partial D}{\partial q_f} = 0 \tag{10}$$

Given that $q_d + q_f = \overline{e}_d + \overline{e}_f$ always holds in equilibrium, we may conclude that $(q_d - \overline{e}_d) = -(q_f - \overline{e}_f)$, so that the two first order conditions imply

$$p^e_{cen} = \frac{\partial D}{\partial q_d}\left(= \frac{\partial D}{\partial q_f}\right) \tag{11}$$

which, together with (5), implies that in under the CETS the number of emission allowances distributed in each country is such to guarantee that the necessary conditions for the maximization of the social welfare function, defined in (1), hold, that is

$$p_q = \frac{\partial c_i(q_i)}{\partial q_i} + \frac{\partial D}{\partial q_i}.$$

□

[8]We assume that (1) is strictly concave, so that the conditions we will state are also sufficient for a maximum.

We move, then, to the main results of the paper, concerning the amount of emission allowances and the overall emissions target set under the DETS. We can start stating the following result:

Lemma 1. *Under the DETS, the "representative" firm located in the high damage country is a permit buyer, while the one located in the low damage country is a permit seller.*

Proof. The FOCs for the welfare maximization problem of the domestic government is[9]

$$\frac{\partial W_d}{\partial \overline{e}_d} = \frac{\partial \Pi_d}{\partial \overline{e}_d} - \beta \left(\frac{\partial D}{\partial q_d} \frac{\partial q_d}{\partial p_e} \frac{\partial p_e}{\partial \overline{e}_d} + \frac{\partial D}{\partial q_f} \frac{\partial q_f}{\partial p_e} \frac{\partial p_e}{\partial \overline{e}_d} \right) = 0$$

that is,

$$p^e - \frac{\partial p_e}{\partial \overline{e}_d}(q_d - \overline{e}_d) - \beta \frac{\partial D}{\partial q_d} = 0, \tag{12}$$

while the FOCs for the foreign government maximization problem is

$$\frac{\partial W_f}{\partial \overline{e}_f} = \frac{\partial \Pi_f}{\partial \overline{e}_f} - (1-\beta) \left(\frac{\partial D}{\partial q_d} \frac{\partial q_d}{\partial p_e} \frac{\partial p_e}{\partial \overline{e}_f} + \frac{\partial D}{\partial q_f} \frac{\partial q_f}{\partial p_e} \frac{\partial p_e}{\partial \overline{e}_f} \right) = 0$$

that is,

$$p^e - \frac{\partial p_e}{\partial \overline{e}_f}(q_f - \overline{e}_f) - (1-\beta) \frac{\partial D}{\partial q_f} = 0 \tag{13}$$

These two conditions are both satisfied in equilibrium where, as in the centralized case, it must be $q_d - \overline{e}_d = -(q_f - \overline{e}_f)$ and $\frac{\partial D}{\partial q_d} = \frac{\partial D}{\partial q_f}$. Therefore, we get the following

$$p^e = \frac{\partial p_e}{\partial \overline{e}_d}(q_d - \overline{e}_d) + \beta \frac{\partial D}{\partial q_d}, \tag{14}$$

and

$$p^e = -\frac{\partial p_e}{\partial \overline{e}_f}(q_d - \overline{e}_d) + (1-\beta) \frac{\partial D}{\partial q_f} \tag{15}$$

[9]Again, we assume that all the relevant conditions for strict concavity of (2) and (3) hold.

Substituting (14) into (15) for p^e we get:

$$\frac{\partial p_e}{\partial \overline{e}_d}(q_d - \overline{e}_d) + \beta\frac{\partial D}{\partial q_d} = -\frac{\partial p_e}{\partial \overline{e}_f}(q_d - \overline{e}_d) + (1-\beta)\frac{\partial D}{\partial q_f}$$

Given that, from (8), $\frac{\partial p_e}{\partial \overline{e}_d} = \frac{\partial p_e}{\partial \overline{e}_f}$, the above equation can be rearranged as follows:

$$\frac{\partial p_e}{\partial \overline{e}_d}(q_d - \overline{e}_d) = \frac{1-2\beta}{2}\frac{\partial D}{\partial q_d} \tag{16}$$

As a consequence, given that $\frac{\partial p_e}{\partial \overline{e}_d} < 0$, we can conclude that:

- when $1-2\beta > 0$, that is $\beta < \frac{1}{2}$, then $(q_d - \overline{e}_d) < 0$ and $(q_f - \overline{e}_f) > 0$
- when $1-2\beta < 0$, that is $\beta > \frac{1}{2}$, then $(q_d - \overline{e}_d) > 0$ and $(q_f - \overline{e}_f) < 0$

□

Notice that this result is in line with proposition 1 in Helm [6]. We can now use the result in Lemma 1 to derive the main proposition of our paper.

Proposition 4. *Under the DETS, permits allocation results in a larger than socially optimal aggregate emissions target, and in a lower than optimal equilibrium price.*

Proof. Substitute from (16) back into (14) (or (15)); we get:

$$p^e_{dec} = \frac{1}{2}\frac{\partial D}{\partial q_d} = \left(\frac{1}{2}\frac{\partial D}{\partial q_f}\right) \tag{17}$$

The equilibrium prices of permits under the two alternative regimes allow us to characterize the optimal level of outputs chosen by the firms in the two countries both under the CETS and under the DETS. Indeed, substituting p^e_{cen} and p^e_{dec} into country i's first order conditions (given in (5)) we get:

$$q_i|_{cen} : p_q - \frac{\partial c_i(q_i)}{\partial q_i} = \frac{\partial D}{\partial q_i} \tag{18}$$

under the CETS and

$$q_i|_{dec} : p_q - \frac{\partial c_i(q_i)}{\partial q_i} = \frac{1}{2}\frac{\partial D}{\partial q_i} \tag{19}$$

under the DETS. We are going to show now that $q_i|_{cen} < q_i|_{dec}$. Suppose not, so that $q_i|_{cen} \geq q_i|_{dec}$. Then, from (18) and (19), and given the convexity of the production cost function, we would have:

$$p_q - \frac{\partial c_i(q_i|_{cen})}{\partial q_i} \leq p_q - \frac{\partial c_i(q_i|_{dec})}{q_i}$$

that is,

$$\frac{\partial D(q_i|_{cen} + q_j|_{cen})}{\partial q_i} \leq \frac{1}{2}\frac{\partial D(q_i|_{dec} + q_j|_{dec})}{\partial q_i} \tag{20}$$

Inequality (20) would require, as a necessary condition, that, $q_j|_{cen} > q_j|_{dec}$, and, therefore,

$$p_q - \frac{\partial c_j(q_j|_{cen})}{\partial q_j} < p_q - \frac{\partial c_j(q_j|_{dec})}{q_j}$$

that is,

$$\frac{\partial D(q_i|_{cen} + q_j|_{cen})}{\partial q_j} < \frac{1}{2}\frac{\partial D(q_i|_{dec} + q_j|_{dec})}{\partial q_j} \tag{21}$$

This is a contradiction; indeed, conditions (20) and (21) cannot be satisfied at the same time, as (11) and (17) require that $\frac{1}{2}\frac{\partial D(q_i|_{dec}+q_j|_{dec})}{\partial q_i}$ $= \frac{1}{2}\frac{\partial D(q_i|_{dec}+q_j|_{dec})}{\partial q_j}$ and that $\frac{\partial D(q_i|_{cen}+q_j|_{cen})}{\partial q_i} = \frac{\partial D(q_i|_{cen}+q_j|_{cen})}{\partial q_j}$. As a consequence, it must be the case that

$$(q_d + q_f)|_{cen} = (\bar{e}_d + \bar{e}_f)|_{cen} < (\bar{e}_d + \bar{e}_f)|_{dec} = (q_d + q_f)|_{dec}.$$

Further, given that (from (8)) $\frac{\partial p^e}{\partial e} < 0$, we can conclude that the equilibrium permits price will be lower under the DETS. □

Proposition 4 shows that, even if firms do not have market power in the output and/or in the permits market, the ability of the two governments to influence the equilibrium permits price, together with the features of international externality of the pollutant we are dealing with, lead the decentralized choice of emissions targets to be distorted with respect to the centralized case. To understand the intuition for this result, we can compare (9) with (12) (and (10) with (13)). Two spillovers among decentralized governments take place. First of all, there is an international externality: by allocating emissions permits the government each country takes into account only a fraction β (or $(1-\beta)$) of the marginal environmental damage caused by its choice. This is a standard, well recognized problem when dealing with transboundary pollution. On the other hand, an increase in the initial allocation of permits in country j also decreases the equilibrium permits price. If country i's "representative" firm is a net seller of permits, then we know from Proposition 2 that this will cause a further negative spillover on country i's welfare. If the "representative" firm operating in country i is a net buyer of permits, then the "price-related" spillover will be positive. Anyway, the *net* spillover must be negative also in this case, in order to ensure that the equilibrium price of permits is strictly positive in a decentralized setting[10]. Summing up, the existence of a net negative spillover between countries leads to the result summed up in Proposition 4 as a logical consequence.

5 Conclusion

In this paper we have addressed the problem of how to allocate emission permits in states belonging to an Economic Union (or to a federal system) when the regulation of transboundary pollution takes place through an emissions trading system. Specifically, we have analyzed a two stage game where governments move first setting the amount of permits to be issued. They can do this acting as a single entity or in a decentralized way. In the second stage each firm observes the amount of permits that have been assigned to it and chooses the level of output and emissions. Emission permits are then traded in a perfectly competitive market.

[10]See footnote 7

In this theoretical framework we have shown that a decentralized setting leads to inefficient results, as there are *net* negative spillovers among national governments related both to the "global" nature of the pollution problem we address and to the fact that, in our setting, governments influence the equilibrium permits' price through their choice concerning national environmental caps. As a consequence, a setting where aggregate environmental quality is the result of a decentralized decision making is likely to lead to distortions with respect to the ideal (centralized) case. This seems to be the case of the European emissions trading system. As a matter of facts, most of the National Allocation Plans that, according to the EU Directive 2003/87/CE, each member state had to submit to the European Commission, originally set an emission cap above the one which would had been consistent with the Kyoto target[11].

Our work could be extended in many directions. First of all it could be interesting to analyze the desirability of decentralization if we also account for the fact that single States might have monitoring cost advantages. Other possible extensions could imply endogenizing the choice between a centralized and a decentralized framework, and/or considering explicitly consumers' surplus in the governments' objective function, introducing another specificity with respect to the standard environmental dumping literature.

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