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ENFORCEMENT AND ENVIRONMENTAL QUALITY IN A DECENTRALIZED EMISSION TRADING SYSTEM

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Enforcement and Environmental Quality in a Decentralized Emission Trading System

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Abstract

This paper addresses the issue of whether the powers of monitoring compliance and allocating allowances under emissions trading within an economic union should be centralized or delegated to single states. To this end, we develop a two stage game played by two governments and their respective polluting industries. Government(s) choose the amount of emission allowances to be issued and set the level of monitoring effort to achieve full compliance, while regulated firms choose actual emissions and the number of permits to be held. We identify various, possibly conflicting, spillovers among countries in a decentralized setting. We show that cost advantage in favor of national states is not sufficient to justify decentralization. Nevertheless, cost differential in monitoring violations can imply lower emissions and greater welfare under a decentralized institutional setting than under a centralized one. However, while a better environmental quality under decentralization is a sufficient condition for higher welfare under the same regime, it is not also a necessary condition.

(**JEL numbers:** F18, K42, Q53. **Keywords:** emissions trading, environmental federalism, enforcement, monitoring cost)

1 Introduction

The degree of decentralization of public policies is a controversial topic. Indeed, while the so called "principle of subsidiarity" claims that it would be better to decentralize to the jurisdictional level which is closer to the preferences of consumers and/or producers, in several circumstances environmental policies may represent important exceptions to this principle (Oates [13]). This paper deals with this issue with a specific focus on emissions trading. More specifically we want to assess to what extent the powers of monitoring compliance and allocating permits within an economic union should be centralized or delegated to the single states.

Under this respect 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) represents an important evidence of a *decentralized* emission trading system (ETS). Indeed, according to the Directive, permits are traded at the Union level, but permits allocation and monitoring duties are left to single member countries. Such a decentralized structure differentiates the EU ETS from the more standard model of emission trading characterized by a central environmental authority that *a)* fixes a cap on total emissions and issues a number of permits equal to the cap, and *b)* decides how to monitor emissions sources in order to enforce full compliance or, at least, minimize under-compliance[1].

The innovative structure of the EU ETS has been attracting the growing interest of environmental economists and some recent insights suggest, on both the theoretical and empirical grounds, that under a *decentralized* ETS member states tend to over-allocate permits (D'Amato and Valentini [4] and Ellerman and Buchner [5]). Nevertheless, one could argue that the inefficiency due to

[1] As an example of a standard, *centralized* ETS we can think about the SO_2 trading system implemented in the US.

over-allocation may be balanced if some monitoring cost advantage exists in favor of single states[2]. The aim of this paper is indeed to investigate this eventuality. Our results suggest that cost differential in monitoring violations can imply lower emissions and greater welfare under a *decentralized* ETS than under a *centralized* one. Nevertheless we also show that cost advantage in favor of national states is not sufficient to justify decentralization.

To derive these results we use a two stage game played by two governments and their respective polluting industries. Governments move first, choosing the emission caps and, as in Malik [11], setting the level of monitoring effort to achieve full compliance [3]. We consider two alternative institutional frameworks, namely a *centralized* ETS, where the two governments act as a single entity, and a *decentralized* ETS, where they play a "Cournot game", that is, each government chooses national caps and the monitoring effort taking other government's choices as given. In the second stage each firm observes the monitoring effort and the emission caps selected by government(s) and chooses its emissions' level.

We conclude that environmental quality is higher under decentralization if the monitoring cost differential is sufficiently high in favor of decentralized governments. This happens because, for a sufficiently high cost differential, the centralized authority has a much stronger incentive than the decentralized ones to issue allowances, in order to drive equilibrium permits price down and to reduce the amount of monitoring needed to achieve full compliance.

Nevertheless, a better environmental quality is not a necessary condition

[2]This assumption can be justified on the basis of the better knowledge that local authorities have concerning the willingness to comply by firms, as well as on the lower costs involved in the use of existing monitoring personnel and facilities.

[3]To assume full compliance is, in our view, close to actuality as, for example, the US SO_2 trading system even achieved overcompliance (see Svendsen [15]) and, if we focus on the EU ETS, the "...initial experience of the learning-by-doing phase of the scheme with respect to compliance and enforcement has been encouraging." (European Commission [6], [p.8])).

for higher welfare under the *decentralized* ETS. As a matter of fact, it may be the case that social welfare is higher under decentralization even if emissions are lower under a centralized authority. This shows that, under certain conditions, a higher emissions level is not, by itself, proof that decentralization of emissions trading is bad, as decentralization could be a good way to tackle monitoring problems in a cost effective way. The overall result, indeed, depends on a number of spillovers between countries that a decentralized allocation mechanism cannot internalize. However, a significant monitoring cost advantage can lead decentralization to higher welfare even if it features higher emissions with respect to a centralized setting. In other words, the cost differential may be sufficient to counterbalance the consequent higher environmental damage that would arise under the *decentralized* ETS.

On the other hand, for the specific functional forms used to carry out our welfare analysis, a better environmental quality under the *decentralized* ETS is a sufficient condition for higher welfare under the same regime. Indeed, when the monitoring cost differential is particularly high in favor of decentralized governments, decentralization features higher environmental quality which is always coupled with higher welfare. This would be, of course the most favorable case that could justify a *decentralized* ETS.

Finally, when the monitoring cost differential is still in favor of decentralized governments but it is not sufficiently high, a decentralized ETS can be justified neither by environmental quality nor by a more general social welfare analysis.

Two strands of the literature deal with questions which are closely related to the issue analyzed in this paper. The first one is related to the so called "environmental dumping" in both international (as in Barrett [1] and Ulph [16]) and federal settings (Ulph [17] and [18]). These papers show how national (or regional) governments attempt to relax environmental policy in order to secure to domestic firms competitive advantages in international markets. Some more recent papers which are close in some sense to the "environmental dumping" literature deals specifically with emission trading. Among them Helm [8] analyzes 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. In another paper, Boom and Dijkstra [2] expand the analysis of Helm [8]. By including boundary solutions they show that in some cases the results presented by Helm do not hold. Finally, D'Amato and Valentini [4] show that a *decentralized* allocation of permits always results 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* solution, and identify spillovers among governments that are new with respect to the received literature and are explicitly vehiculated by the emission permits price. Our modelling strategy follows the one adopted by the environmental dumping literature, but government(s) do not only choose the amount of allowances to be issued but also the level of monitoring and enforcement effort to be devoted to discover and punish non compliant firms, as in the emission permits enforcement literature.

The second strand of the literature to which our paper is strictly related is the one on non-compliance under emission trading systems, starting with Malik [10] and Keeler [9]. The authors examine the consequences of noncompliance for a permits market, revealing that when firms are noncompliant permits markets may not retain their efficiency properties. In a subsequent work, Malik [11] includes explicitly enforcement costs in the comparison among incentive based policies and standard command and control instruments, and conclude that the ranking among the two kinds of instruments is not obvious in such a setting. These papers are then exteded, among others, by Van Egteren and Weber [19], Malik [12] and Chavez and Stralund [3] to account for the interaction among the chance for non compliance and the presence of market power. We also contribute to this strand of literature since, to our knowledge, this is the first attempt to investigate the consequences of decentralization when the choice of enforcement effort is accounted for.

While the main features of the 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 choices, while section 5 provides a more detailed description of results by assuming specific functional forms. Finally, section 6 concludes.

2 The model

We analyze a stylized model representing an Economic Union formed by two countries (a domestic one, labelled as d, and a foreign one, labelled as f). In each country there is a large number of identical firms. 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). We consider two alternative institutional frameworks, namely a *centralised* one, where the governments of the two countries act as a single entity and maximize aggregate social welfare, and a *decentralised* one, where each government maximizes domestic welfare.

The interactions among the two firms and the governments are defined by the following two stage game. In the first stage, the two governments choose jointly - under the *centralised* institutional framework - or separately - under the *decentralised* one - the emissions caps $\overline{e}_i$ and the monitoring efforts required to to achieve full compliance u_i, i $(i = d, f)$.

Given the governments' choices, in the second stage, the firms choose actual emissions (e_d and e_f) and permits holding (q_d and q_f) in order to maximize expected profits, i.e.

$$\max_{e_i,q_i} \pi_i = B_i(e_i) - p_e(q_i - \overline{e}_i) - N(u_i, v_i), (i = d, f)$$

where $B_i(e_i)$ is a strictly increasing and concave function of benefits deriving from emissions (excluding permits and fine payments).

Firms do not have market power in the permits market. Then, firms face an (exogenous) price p_e for permits. Each firm receives an (exogenous) initial endowment of permits, $\overline{e}_i$. Accordingly, $p_e(q_i - \overline{e}_i)$ represents the sum of money the firm spends (earns) if it is a net buyer (seller) of permits and the resulting aggregate environmental standard is given by $\overline{e} = \overline{e}_d + \overline{e}_f$. We can assume, without loss of generality, that overcompliance never takes place[4]; as a consequence, if $q_i = e_i$, then there is no violation (defined as $v_i = e_i - q_i$) and the firm is perfectly compliant, while if $v_i > 0$, that is, if $e_i > q_i$, then the firm is non compliant.

As in Malik [10] we assume that the firm is audited in an unexpected way and cannot vary permits' holding after realizing. The audit probability depends on the effort u_i devoted to monitoring and enforcement as well as on the degree of violation, while the fine depends non linearly on the violation. The expected fine function is defined by $N_i(v_i, u_i)$ which is assumed to be increasing in the violation, i.e. $\frac{\partial N_i}{\partial v_i} > 0$, and in the degree of monitoring, i.e. $\frac{\partial N_i}{\partial u_i} > 0$. We also impose that $\frac{\partial^2 N(u_i,v_i)}{\partial v_i^2} > 0$, which is reasonable, in order for second order conditions to be satisfied.

In the following two sections we solve this game at its different stages in order to identify the subgame perfect Nash equilibria.

[4]In our simple model, overcompliance would indeed imply the equilibrium permits price to be driven to 0.

3 The firms' problem

The firms' first order conditions w.r.t. e_i are:

$$\frac{\partial B_i(e_i)}{\partial e_i} - \frac{\partial N(u_i, v_i)}{\partial v_i} = 0$$

while those w.r.t. q_i are:

$$-p_e + \frac{\partial N(u_i, v_i)}{\partial v_i} = 0$$

Comparative statics with respect to the permits price leads to the following:

Result 1 *Both emissions and permits' holding decrease in the price of permits but, as a whole, compliance increases in the price of permits.*

Proof. Note that

$$\frac{de_i}{dp_e} = \frac{1}{\frac{\partial^2 B_i(e_i)}{\partial e_i^2}} < 0$$

and

$$\frac{dq_i}{dp_e} = -\frac{1}{\frac{\partial^2 N(u_i,v_i)}{\partial v_i^2}} + \frac{1}{\frac{\partial^2 B_i(e_i)}{\partial e_i^2}} < 0.$$

As a consequence, $\left|\frac{dq_i}{dp_e}\right| > \left|\frac{de_i}{dp_e}\right|$, so that

$$\frac{dv_i}{dp_e} = \frac{de_i}{dp_e} - \frac{dq_i}{dp_e} > 0.$$

■

Comparative statics with respect to the monitoring effort leads to the following:

Result 2 *The level of actual emissions does not depend* directly *on the degree of monitoring effort.*

Proof. Simply note that

$$\frac{de_i}{du_i} = \frac{-\frac{\partial^2 N(u_i,v_i)}{\partial v_i^2}\frac{\partial^2 N(u_i,v_i)}{\partial u_i \partial v_i} + \frac{\partial^2 N(u_i,v_i)}{\partial u_i \partial v_i}\frac{\partial^2 N(u_i,v_i)}{\partial v_i^2}}{-\frac{\partial^2 N(u_i,v_i)}{\partial v_i^2}\frac{\partial^2 B_i(e_i)}{\partial e_i^2}} = 0$$

■

This result is not really new in the literature. Indeed, both in Malik [10] and, for the case of a firm facing emissions taxes, in Harford [7] the emissions' choice is independent of the probability that the firm is monitored. Strandlund and Dhanda [14], moreover, show that this independence extends also to the enforcement pressure. Our very general definition of $N_i(v_i, u_i)$, however, allows to note that the independence from the monitoring effort (that may be thought as the result of an unspecified mix of both audit probability and enforcement pressure) does not depend on the linearity of the expected penalty in the monitoring effort which is assumed by both Malik [10] and Strandlund and Dhanda [14]. Result 2 does not imply that monitoring effort cannot influence actual emissions at all. Indeed, we can also show that

Result 3 *An increase in monitoring effort causes permits demand to increase and the same happens to the equilibrium permits price.*

Proof. If $\frac{\partial N(u_i,v_i)}{\partial u_i \partial v_i} > 0$ that is, if the marginal increase in expected penalty due to an increase in the violation increases with monitoring effort, then

$$\frac{dq_i}{du_i} = \frac{\frac{\partial^2 N(u_i,v_i)}{\partial u_i \partial v_i}}{\frac{\partial^2 N(u_i,v_i)}{\partial v_i^2}} > 0$$

that, in turn, can be used to show that also the sign of $\frac{dp_e}{du_i}$ is positive. The equilibrium on the permits market implies:

$$q_d + q_f = \overline{e}$$

and, as $d\overline{e} = 0$, comparative statics imply:

$$\frac{\partial q_d}{\partial p_e}dp_e + \frac{\partial q_d}{\partial u_d}du_d + \frac{\partial q_f}{\partial p_e}dp_e + \frac{\partial q_f}{\partial u_f}du_f = 0$$

that is,

$$\frac{dp_e}{du_i} = -\frac{\frac{\partial q_i}{\partial u_i}}{\frac{\partial q_i}{\partial p_e} + \frac{\partial q_j}{\partial p_e}} > 0$$

for any $i, j = d, f$, $i \neq j$. ■

Therefore, immediate corollaries of results 1 and 3 are that, as noted by both Malik [10] and Strandlund and Dhanda [14], an increase in the monitoring effort *indirectly* decreases actual emissions *via* its effect on the permits price, and that the violation is strictly decreasing in the monitoring effort, i.e.:

$$\frac{dv_i}{du_i} = -\frac{dq_i}{du_i} < 0.$$

Finally, we can state and prove the following

Result 4 *Increasing the monitoring effort to the "representative" firm operating in country i makes the same firm worse off*

- *always, when the firm itself is a net permits buyer*
- *only if* $|\frac{\partial N(u_i,v_i)}{\partial u_i}| > |\frac{\partial p_e}{\partial u_i}(q_i - \overline{e}_i)|$, *when the firm itself is a net seller.*

Increasing the monitoring effort to the "representative" firm operating in country j makes the firm operating in country i worse off

- *always, when the firm itself is a net permits buyer*
- *never, when the firm itself is a net seller.*

Proof. To show this result we need to derive firms' expected profits w.r.t. both the monitoring effort directly addressed to them and the monitoring effort addressed to the other. Then, the first type of derivative is

$$\frac{\partial \pi_i}{\partial u_i} = \frac{\partial B_i(e_i)}{\partial e_i}\left(\frac{\partial e_i}{\partial p_e}\frac{\partial p_e}{\partial u_i} + \frac{\partial e_i}{\partial u_i}\right) - \frac{\partial p_e}{\partial u_i}(q_i - \overline{e}_i) - p_e\left(\frac{\partial q_i}{\partial p_e}\frac{\partial p_e}{\partial u_i} + \frac{\partial q_i}{\partial u_i}\right) + \\ - \frac{\partial N(u_i,v_i)}{\partial u_i} - \frac{\partial N(u_i,v_i)}{\partial v_i}\left(\frac{\partial e_i}{\partial p_e}\frac{\partial p_e}{\partial u_i} + \frac{\partial e_i}{\partial u_i} - \frac{\partial q_i}{\partial p_e}\frac{\partial p_e}{\partial u_i} - \frac{\partial q_i}{\partial u_i}\right)$$

As in equilibrium $\frac{\partial B_i(e_i)}{\partial e_i} = p_e$, we can rewrite the derivative as:

$$\frac{\partial \pi_i}{\partial u_i} = \frac{\partial B_i(e_i)}{\partial e_i}\left(\frac{\partial e_i}{\partial p_e}\frac{\partial p_e}{\partial u_i} - \frac{\partial q_i}{\partial p_e}\frac{\partial p_e}{\partial u_i} + \frac{\partial e_i}{\partial u_i} - \frac{\partial q_i}{\partial u_i}\right) - \frac{\partial p_e}{\partial u_i}(q_i - \overline{e}_i) +$$
$$- \frac{\partial N(u_i, v_i)}{\partial u_i} - \frac{\partial N(u_i, v_i)}{\partial v_i}\left(\frac{\partial e_i}{\partial p_e}\frac{\partial p_e}{\partial u_i} + \frac{\partial e_i}{\partial u_i} - \frac{\partial q_i}{\partial p_e}\frac{\partial p_e}{\partial u_i} - \frac{\partial q_i}{\partial u_i}\right)$$

and, for the envelope theorem:

$$\frac{\partial \pi_i}{\partial u_i} = -\frac{\partial p_e}{\partial u_i}(q_i - \overline{e}_i) - \frac{\partial N(u_i, v_i)}{\partial u_i}$$

which is always negative when $q_i > \overline{e}_i$, while the sign will be ambiguous if $q_i < \overline{e}_i$,.

The other derivative is

$$\frac{\partial \pi_i}{\partial u_j} = \frac{\partial B_i(e_i)}{\partial e_i}\frac{\partial e_i}{\partial p_e}\frac{\partial p_e}{\partial u_j} - \frac{\partial p_e}{\partial u_j}(q_i - \overline{e}_i) - p_e\frac{\partial q_i}{\partial p_e}\frac{\partial p_e}{\partial u_j} - \frac{\partial N(u_i, v_i)}{\partial v_i}\left(\frac{\partial e_i}{\partial p_e}\frac{\partial p_e}{\partial u_j} - \frac{\partial q_i}{\partial p_e}\frac{\partial p_e}{\partial u_j}\right).$$

With the same arguments, this can be rewritten as

$$\frac{\partial \pi_i}{\partial u_j} = -\frac{\partial p_e}{\partial u_j}(q_i - \overline{e}_i)$$

which is negative (positive) only when $(q_i - \overline{e}_i)$ is positive (negative). ■

We can therefore conclude that an increase in monitoring in country j can lead to a decrease or an increase in firm's profits in country i *via* the permits' price. This could be seen as a first source of spillovers among countries that national governments could not take into account when they separately set the number of permits and the monitoring effort. However, given that the permits' market must be in equilibrium, then this spillover is likely to cancel in equilibrium.

4 Government(s) problem

The centralized government chooses both emission allowances and the monitoring effort levels to be allocated to the firms in the two countries in order to achieve full compliance. To induce firms to be fully compliant, the monitoring efforts applied to them must be such that the following condition holds

$$p_e = \frac{\partial N(u_i^F, 0)}{\partial v_i}$$

that is, the marginal fine corresponding to full compliance must be equal to the permits price. The above condition implicitly defines $u_i^F(p_e)$, the monitoring effort to achieve full compliance. Comparative statics imply that $\frac{\partial u_i^F(p_e)}{\partial p_e} > 0$.

$$\max_{\overline{e}_d, \overline{e}_f} W = \pi_d + \pi_f - c_d(u_d^F) - c_f(u_f^F) - D_d(e_d + e_f) - D_f(e_d + e_f)$$

that is, total profits *minus* monitoring costs *minus* social costs related to environmental damages. The costs of monitoring effort are given by $c_i(u_i)$ with $c_i' > 0$ and $c_i'' > 0$. The damages from pollution are defined, for country i, as $D_i(e_d + e_f)$ with $D_i' > 0$ and $D_i'' > 0$. Notice that we allow for transboundary pollution.

Since fines are a net transfer and, in a centralized setting, the same holds for permits revenues or costs, the objective function of the centralized government can be rewritten as follows:

$$W = B_d(e_d) + B_f(e_f) - c_d(u_d^F) - c_f(u_f^F) - D_d(e_d + e_f) - D_f(e_d + e_f) \quad (1)$$

Also in the decentralized case the expected fine is a net transfer. Government i chooses therefore the amount of allowances to be issued to domestic firms and the monitoring effort to achieve full compliance according to the following maximand:

$$W_i = \pi_i - \psi_i(u_i^F) - D_d(e_i + e_j)$$

that is,

$$W_i = B_i(e_i) - p_e(e_i - \overline{e}_i) - \psi_i(u_i^F) - D_i(e_i + e_j) \quad (2)$$

where $\psi_i(.)$ are monitoring costs under decentralization.

At this level of generalization, the necessary and sufficient conditions for such maximization problems do not provide many "readable" insights. Nevertheless, we can identify a number of spillovers that national authorities would not take into account when, under decentralization, they independently choose the amount of permits to be allocated.

Indeed,

$$\frac{\partial W_j}{\partial \overline{e}_i} = -\frac{\partial p_e}{\partial \overline{e}_i}(e_j - \overline{e}_j) - \left(\frac{\partial D_j}{\partial e_i}\frac{\partial e_i}{\partial p_e} + \frac{\partial D_j}{\partial e_j}\frac{\partial e_j}{\partial p_e}\right)\frac{\partial p_e}{\partial \overline{e}_i} - \frac{\partial \psi_j(u_j)}{\partial u_j}\frac{\partial u_j^F}{\partial p_e}\frac{\partial p_e}{\partial \overline{e}_i} = 0 \tag{3}$$

1. The term $-\frac{\partial p_e}{\partial \overline{e}_i}(e_j - \overline{e}_j)$ is due to the fact that an increase in the initial allocation of permits in country i also decreases the equilibrium permits price. If country j's "representative" firm is a net seller of permits, this will cause a negative spillover on country j's welfare. If the "representative" firm operating in country j is a net buyer of permits, this spillover will be positive. The overall effect among the two countries cancels out, however, because, when the permits market is in equilibrium, the positive spillover in one country perfectly offsets the negative spillover in the other. Such spillover is therefore likely to have only distributional consequences.

2. The term $-\left(\frac{\partial D_j}{\partial e_i}\frac{\partial e_i}{\partial p_e} + \frac{\partial D_j}{\partial e_j}\frac{\partial e_j}{\partial p_e}\right)\frac{\partial p_e}{\partial \overline{e}_i}$ captures a second spillover: this is an international externality that the choice of the environmental authority of country i causes to country j. As we know, an increase in permits by any country leads to an increase in emissions that will also damage the other country. However, it is worthwhile to note that this externality is a consequence of the permits' market *per se*, and it does not depend on the global nature of the environmental issue we are dealing with. As a matter of fact, even if the environmental damages of the two countries

depended only on the emissions generated within their borders an increase in $\overline{e}_i$ would still bring about more emissions in country j *via* the induced reduction in p_e. This effect is discussed in detail by [4].

3. The term $-\frac{\partial \psi_j(u_i)}{\partial u_j}\frac{\partial u_j^F}{\partial p_e}\frac{\partial p_e}{\partial \overline{e}_i}$ identifies a positive spillover among countries: an increas in permits endowment in country i leads to a decrease in equilibrium permits price and, therefore, to a decrease in the amount of monitoring effort needed to achieve full compliance, leading to a reduction in related costs.

The net effect of the three spillovers is not obvious. Further the cost differential among the centralized and the decentralized settings must be accounted for. Therefore, to achieve a better understanding of the net effect of such spillovers, in the next section we impose specific functional forms and solve the game for the corresponding subgame perfect equilibrium.

5 The consequences of decentralization

5.1 Firms' problem

To keep matters simple, we assume that there is complete symmetry among countries. We assume for country i $(i = d, f)$ the following specific shapes for the expected benefits and expected fine functions:

$$B(e_i) = e_i - \frac{e_i^2}{2}$$

and

$$N_i(u_i, v_i) = \begin{cases} u_i\left(F(q_i - e_i) + \frac{1}{2}(q_i - e_i)^2\right) & \text{for } q_i > e_i \\ 0 \text{ otherwise} \end{cases}$$

where α and F are positive constants. Using the above functional forms and solving the firms' maximization problem we get:

$$q_i = 1 - p_e$$

$$e_i = 1 + F - \frac{1+u}{u} p_e$$

The level of violation is therefore given by the following expression:

$$v_i = q_i - e_i = \frac{p_e}{u_i} - F \tag{4}$$

Equilibrium on the permits market implies[5]:

$$p_e = \frac{u_i u_j}{u_i + u_j + 2u_i u_j} \left(2 + 2F - \overline{e}\right)$$

5.2 First stage: the governments

As already outlined, we assume that the level of monitoring effort is chosen in order to achieve full compliance. In order for firms' violation to be 0, from (4) it must be the case that:

$$u_i F = u_j F = p_e$$

so that full compliance is only possible if $u_i = u_j = u$.

As a consequence, substituting in the equilibrium price of permits we get:

$$p_e = \frac{u}{2(1+u)} \left(2(1+F) - \overline{e}\right)$$

: and

$$u = \frac{1}{2F} \left(2 - \overline{e}\right)$$

Substituting back in p_e, we get therefore:

$$p_e = 1 - \frac{1}{2}\overline{e}$$

Given full compliance the expected fine is 0, and $q = e$.

[5] The equilibrium price is positive when $2F - \overline{e} + 2 > 0$. We assume this is the case.

5.3 Centralized case

In the centralized case the objective function is given by benefits from emissions minus environmental costs minus enforcement costs. Given full compliance the expected fine is 0. The net selling or buying behaviour on the permits market cancel on aggregate. As a consequence, the centralized case objective function is:

$$W = 2e\left(1-e\right) - \left(\overline{e}\right)^2 - 2\lambda u$$

Notice that we dropped indexes i and j because emission choices are symmetric across firms. We also assumed a linear shape for the monitoring cost function, that is, $c_i(u_i) = \lambda u_i$ for all i. Such objective function can be rewritten as.

$$W = \frac{1}{4F}\left(4F\overline{e} - 8\lambda + 4\overline{e}\lambda - 5F\overline{e}^2\right)$$

The maximization of W leads, after simple manipulation of first order (necessary and sufficient) conditions, to

$$\overline{e}_c = \frac{1}{5F}\left(2F + 2\lambda\right)$$

which is the aggregate cap in the centralized case.

The resulting equilibrium permits price is[6]:

$$p_e^c = \frac{1}{5F}\left(4F - \lambda\right)$$

and emissions by each firm are:

$$e_c = \frac{1}{5F}\left(F + \lambda\right)$$

The needed monitoring effort to guarantee full compliance will be

$$u_c = \frac{1}{5F^2}\left(4F - \lambda\right)$$

Finally, we turn to expected welfare that, after some simple manipulations, is:

$$W_c = \frac{1}{5F^2}\left(F^2 - 8F\lambda + \lambda^2\right)$$

[6] In order to guarantee that price of permits is not driven to 0, we must assume that $\lambda < 4F$.

5.4 Decentralized case

The objective function of government i can be written as profits net of permits costs (revenues) minus the fraction of environmental costs born by country i minus enforcement costs:

$$W_i = q_i - \frac{e_i^2}{2} - p_e(e_i - \overline{e}_i) - \frac{1}{2}(e_i + e_j)^2 - \lambda_i u_i$$

where, again, the monitoring costs are assumed to be linear (i.e. $\psi_i(u_i) = \lambda_i u_i$), while each country is assumed to bear exactly half of the environmental costs, so that an asymmetry that is not meaningful for our results is removed from the model. Another asymmetry we remove is related to asymmetries in monitoring costs among countries. More specifically, we assume that $\lambda_d = \lambda_f = \lambda_n$.

Taking the FOCs w.r.t $\overline{e}_i$ and rearranging, we get the following reaction funtion for country i :

$$\overline{e}_i = \frac{1}{7F}(4F - 5F\overline{e}_j + 2\lambda_n)$$

Following the same reasoning as for country d, we get the following reaction function for government f:

$$\overline{e}_j = \frac{1}{7F}(4F - 5F\overline{e}_i + 2\lambda_n)$$

Solving for the Nash equilibrium we get:

$$\overline{e}_d = \frac{1}{6F}(2F + \lambda_n)$$

and

$$\overline{e}_f = \frac{1}{6F}(2F + \lambda_n)$$

The corresponding aggregate standard is:

$$\overline{e}_n = \overline{e}_d + \overline{e}_f = \frac{1}{3F}(2F + \lambda_n)$$

while the resulting equilibrium permits price is as follows[7]:

$$p_e^n = \frac{1}{6F}(4F - \lambda_n)$$

Finally, the monitoring effort needed to achieve full compliance and emissions are given by the following expression, respectively:

$$u_n = \frac{1}{6F^2}(4F - \lambda_n)$$

$$e_n = \frac{1}{6F}(2F + \lambda_n)$$

The resulting social welfare is (after some manipulations):

$$W_n = \frac{1}{36F^2}\left(4F^2 - 56F\lambda_n + 7\lambda_n^2\right)$$

5.5 Comparisons

In order to make comparisons easier, we assume the following relationship between centralized and decentralized monitoring costs:

$$\lambda = \eta\lambda_n$$

where

- when $\eta \in (0, 1)$ monitoring is more costly under decentralization, while
- when $\eta \in (1, \infty)$ there is a cost advantage in favour of decentralized governments.

The comparison of aggregate caps arising under centralization and in a decentralized setting leads to the following result:

$$\Delta\overline{e} = \overline{e}^n - \overline{e}^c = \frac{1}{15F}(5\lambda_n + 4F - 6\lambda_n\eta)$$

[7] The assumption that equilibrium permits price is positive implies, under decentraliztion, $\lambda_n < 4F$.

which is negative, implying a higher cap in the centralized case, if

$$\eta > \frac{1}{6\lambda_n}\left(4F + 5\lambda_n\right) = \eta_e$$

where it is easily shown that $\eta_e > 1$.

We can therefore state the following Proposition:

Proposition 1 *A sufficiently high cost differential in favor of the decentralized governments leads the aggregate cap to be higher under centralization. More specifically, in our modeling framework, we get the following two cases:*

- *if* $0 < \eta < \eta_e$ *then* $\Delta\bar{e} > 0$
- if $\eta > \eta_e$ then $\Delta\bar{e} < 0$.

The intuition for this result is as follows; when the cost differential is very high then the "differential" incentive of the centralized government to decrease permits price to achieve full compliance with lower monitoring effort is so strong to counterbalance any negative spillover among countries related to emissions. When the cost differential is not very high, the opposite happens.

Turning to welfare comparison we get:

$$\Delta W = W^n - W^c = \frac{1}{180}\frac{35\lambda_n^2 + 288\eta\lambda_n F - 16F^2 - 280F\lambda_n - 36\eta^2\lambda_n^2}{F^2}.$$

Introduce the following notation: $\eta_W^1 = \frac{1}{6}\frac{24F-\sqrt{35}(4F-\lambda_n)}{\lambda_n}$; $\eta_W^2 = \frac{1}{6}\frac{24F+\sqrt{35}(4F-\lambda_n)}{\lambda_n}$.

It is easily shown that $\eta_W^2 > \eta_e > \eta_W^1 > 1$ and that $\eta_W^2 > \frac{4F}{\lambda_n}$. As a consequence, we can never have the case that $\eta > \eta_W^2$ as it would imply a null (centralized) equilibrium permits price.

This leads us to the following Proposition.

Proposition 2 *When centralization implies sufficiently higher monitoring costs w.r.t. a decentralized setting, the latter results in a higher social welfare. More specifically*

- $\Delta W < 0$ *for* $\eta < \frac{1}{6}\frac{24F-\sqrt{35}(4F-\lambda_n)}{\lambda_n}$
- $\Delta W > 0$ *for* $\frac{1}{6}\frac{24F-\sqrt{35}(4F-\lambda_n)}{\lambda_n} < \eta < \frac{4F}{\lambda_n}$

Results in propositions 1 and 2 can be summed up in three possible cases:

1. $\Delta W < 0$ and $\Delta\bar{e} > 0$ for $\eta < \eta_W^1$

   In this case the cost differential is sufficiently low to keep emissions higher in a decentralized setting. The cost advantage under decentralization is not enough to counterbalance the related environmental damage in terms of social welfare.

2. $\Delta W > 0$ and $\Delta\bar{e} > 0$ for $\eta_W^1 < \eta < \eta_E$

   In this case emissions are higher in a decentralized setting, but decentralization also features a higher welfare. This could be the case because the cost differential is now higher in favour of a decentralized setting.

3. $\Delta W > 0$ and $\Delta\bar{e} < 0$ for $\eta_E < \eta < \frac{4F}{\lambda_n}$

   In this third case emissions are even higher under centralization. This is the most favourable case for decentralization.

6 Conclusion

In the paper, we have addressed the consequences of decentralizing compliance monitoring and permits allocation under emissions trading within an economic union. Using a two stage game played by two governments, and their respective polluting industries, we identified various spillovers among countries arising under decentralization.

Further steps for improving the study presented in this paper could be the extension of results to a more general setting where no explicit functional form is introduced, the removal of the symmetry assumptions among countries, and the explicit modeling of the output market. Despite of these limits, by simply introducing the possibility of monitoring costs differential between national environmental authorities and a centralized one operating at the Union level we have have been able to show that decentralization is not necessarily an inefficient political choice. Indeed, high cost differential in monitoring violations can imply lower emissions and greater welfare under a decentralized institutional setting than under a centralized one. This result is particularly relevant since it allows to find an economic justification for decentralization which is based on efficiency and not on other political arguments as in D'Amato and Valentini [4].

On the other hand, we have also seen that cost advantage in favor of national states is not sufficient to justify decentralization. As a consequence, the entity of possible cost differentials (if any) should be carefully evaluated in order to express any definitive judgement on the two alternative emission trading regimes.

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