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Summary

This paper addresses the issue of whether the powers of monitoring compliance and allocating tradeable emissions allowances within a federation of countries should be appointed to a unique federal regulator or decentralized to several local regulators. To this end, we develop a two stage game played by environmental regulator(s) and the polluting industries of two countries. Regulator(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 states in a decentralized setting. We show that cost advantage in favor of local regulators 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.

Keywords: Emissions Trading, Environmental Federalism, Enforcement, Monitoring Cost

JEL Classification: F18, K42, Q53

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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 [14]). 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 a federation of states 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 states. 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 [5] and Ellerman and Buchner [6]). Nevertheless, one could argue that the inefficiency due to 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 single states' regulators is not sufficient to justify decentralization.

To derive these results we use a two stage game played by environmental regulators and polluting industries. Regulators move first, choosing the emission caps and, as in Malik [12], setting the level of monitoring effort to achieve full compliance [3]. We deal with a federation of two countries under two alternative

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

[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. See also [3], where decentralization is justified, among other things, in terms of centralized diseconomies of scale in administration and technical expertise.

[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 [16]) and, if we focus on the EU ETS, the "...initial experience of the learning-by-doing phase of the scheme with respect to

institutional frameworks, namely a *centralized* ETS, where there is a unique federal regulator, and a *decentralized* ETS, where there are two local regulators playing a "Cournot game", that is, each regulator chooses the emissions cap and the monitoring effort taking other regulator's choices as given[4]. In the second stage each firm observes the monitoring effort and the emission caps selected by regulator(s) and chooses its emissions' level.

We find that, under full compliance, emissions allocation in one country causes a number of conflicting spillovers to the other country that a decentralized regulatory mechanism cannot internalize. Three spillovers are particularly relevant: the first one is defined in the paper as *pollution spillover*, causing lower environmental quality and lower welfare in the other country; the second is named *enforcement spillover*, causing higher environmental quality and higher welfare in the other country; finally, we have a third, crucial spillover that may cause opposite effects on environmental quality and welfare of the other country depending on the sign of the asymmetry in monitoring cost between the centralized regulator and the decentralized ones.

We conclude that environmental quality can be higher under decentralization only if some monitoring cost differential is accounted for. Indeed, when there is no asymmetry between countries and between local and federal regulators, the third spillover cancels out, the pollution spillover always prevail over the enforcement one, and decentralization always leads to higher emissions and lower welfare. Similarly, when the monitoring cost differential is in favor of decentralized regulators but it is not sufficiently high, yet a decentralized ETS can be justified neither by environmental quality nor by a more general social welfare analysis.

Environmental quality is higher under decentralization only if the monitoring cost differential is sufficiently high in favor of decentralized regulators. Nevertheless, for specific functional forms used to carry out some additional welfare analysis, we show that a better environmental quality is not a necessary condition 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 regulator. 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. Indeed, the cost differential may be sufficient to counterbalance the consequent higher environmental damage that would arise under the *decentralized* ETS.

On the other hand, 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 regulators, 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.

compliance and enforcement has been encouraging." (European Commission [7], [p.8])).

[4]In the paper we will discuss the implications of decentralization in a federal state, but our results would hold unchanged if the focus were on an Economic Union.

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 [17]) and federal settings (Ulph [18] and [19]). These papers show how national regulators 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 [9] 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 [9]. By including boundary solutions they show that in some cases the results presented by Helm do not hold. Finally, D'Amato and Valentini [5] 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. Our modelling strategy follows the one adopted by the environmental dumping literature, but regulator(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 [11] and Keeler [10]. 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 [12] 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 extended, among others, by Van Egteren and Weber [20], Malik [13] and Chavez and Stralund [4] 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.

The rest of the paper is organized as follows. The main features of the model are presented in the next section. Section 3 derives the solutions of both the games defined under the decentralized and the centralized settings. Section 4 presents a number of results based on some comparative statics. The centralized and the decentralized regimes are compared in section 5 in terms of both environmental quality and social welfare. Finally, section 6 concludes.

2 The model

We analyze a stylized model representing an Economic Union formed by two countries labelled as A and B. In each country i ($i = A, B$) there are a large number of identical firms. By normalizing to 1 the number of firms in each country, we deal with one "representative" firm in each country (firm A and firm B). We model two alternative institutional frameworks, namely a decentralized emissions trading system ($DETS$) and a centralized one ($CETS$). Under the $DETS$, we have a national environmental regulator in each country i ($i = A, B$) while, under the $CETS$ there is a single supranational regulator operating at the Union level.

Before defining the interactions among the two firms and the regulator(s), let us define

- e_i as the level of actual polluting emissions generated by firm i; pollution is assumed to be uniformly mixing;
- $\overline{e}_i$ as the initial endowment of permits received by firm i;
- q_i as the level of allowed emission, that is the level of permits held by firm i;
- $v_i = e_i - q_i$ as the level of violation that can be chosen by firm i. When $v_i = 0$ there is no violation and the firm is perfectly compliant, while, the firm is non compliant whenever $v_i > 0$[5];
- u_i as the level of monitoring effort required to induce firm i to be fully compliant;
- p is the price for permits resulting from a competitive market operating at the Economic Union level.

The interactions among the two firms and the regulators are characterized by the following two stage games of complete (but imperfect) information defined separately for the ($DETS$) and the ($CETS$).

2.1 The two stage game under the *DETS*

First stage: Each regulator i ($i = A, B$) chooses the level of monitoring effort (u_i) in order to induce firm i to be fully compliant and the levels of emissions permits allocated to firm i ($\overline{e}_i$) in order to maximize the national social welfare

$$W_i = \pi_i - \psi_i - D_i \tag{1}$$

where $i = A, B$ and

[5] We assume, without loss of generality, that overcompliance, that is $v_i < 0$, never takes place. In our simple model, any level of overcompliance would just imply the equilibrium permits price to be driven to 0.

- π_i is the expected profit of firm i that will be better defined at the second stage;
- $\psi_i = \psi_i(u_i)$ is the cost of monitoring firm i under decentralization, with $\psi_i' > 0$ and $\psi_i'' > 0$;
- $D_i = D_i(e)$, is the damage to country i caused from the uniformly mixed pollution e defined as $e = e_A + e_B$, and where $\frac{dD_i}{de} > 0$ and $\frac{d^2 D_i}{de^2} > 0$ $(i = A, B)$.

Second stage: Each firm i $(i = A, B)$ chooses actual emissions (e_i) and permits holding (q_i) in order to maximize its expected profit

$$\pi_i = B_i - p(q_i - \overline{e}_i) - N_i, \tag{2}$$

where $i = A, B$ and

- $B_i = B_i(e_i)$ is a strictly increasing and concave function of benefits deriving from emissions (excluding permits and fine payments);
- $p(q_i - \overline{e}_i)$ is the sum of money the firm spends (earns) if it is a net buyer (seller) of permits where, given competitiveness in the permits market, p is exogenously faced by firms.
- $N_i = N(u_i, v_i)$ represents firm i's expected fine function[6] 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. $\frac{\partial N_i}{\partial u_i} > 0$[7]. 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. Finally, $\frac{\partial N(u_i,v_i)}{\partial u_i \partial v_i} > 0$, that is, the marginal increase in expected penalty due to an increase in the violation increases with monitoring effort.

It is worthwhile to note that the expected fine is a net transfer from the firms to the regulator, then it can be omitted in the national social welfare function (1).

2.2 The two stage game under the *CETS*

First stage: The centralized regulator chooses the levels of u_A and u_A in order to induce firm A and firm B, respectively, to be full compliant, and the levels of $\overline{e}_A$ and $\overline{e}_B$ required to maximize the aggregate social welfare

$$W = \pi_A + \pi_B - c_A - c_B - D_A - D_B \tag{3}$$

where

[6] As in Malik [11] we assume that the firm is audited in an unexpected way and cannot vary permits' holding after realizing.

[7] If we think about the expected fine as product of the fine times the audit probability, then we can suppose that the audit probability depends on the degree of violation as well as on the effort u_i, and that the fine depends non linearly on the violation.

- π_i is the expected profit of firm's i ($i = A, B$) that has been already defined in section 2.1;
- $c_i = c_i(u_i)$ is the centralized regulator's cost of monitoring firm i, with $c_i' > 0$ and $c_i'' > 0$;
- $D_i = D_i(e)$, is the damage caused from pollution to country $i(i = A, B)$ that has been already defined in section 2.1.

Also in the centralized case the expected fine is a net transfer....

Second stage: It is exactly the same as in section 2.1.

Of course, also under the *CETS* the expected fine is a net transfer from the firms to the regulator. Then, it can be omitted also in the aggregate social welfare function (3).

2.3 The market of permits

In this game the equilibrium price of permits is implicitly defined by the following market clearing condition[8]:

$$q_A + q_B = \overline{e}_A + \overline{e}_B \tag{4}$$

where the total amounts of permits held by the firms, on the left hand side, and total endowment of permits allocated to the firms, on the right hand side, represent the demand and the supply of permits respectively.

The demand side is defined by the conditions characterizing the optimal choices of the firms in the second stage of the game while the supply side is defined in the first stage of the game when the environmental regulators choose (at federal or national level) the amount of emission allowances to be issued to the two "representative" firms, taking into account how firms will react in the second stage. In so doing the regulators realize that the equilibrium price in the permits market can be influenced by their choice of $\overline{e}_i$ ($i = A, B$), while firms face an exogenous price p because they do not have market power in the permits market.

3 The solutions of the games

In this section we first solve the two games defined under the *DETS* and under the *CETS* in order to characterize the price of permits under the two alternative regulatory settings.

3.1 The solution of the game under the *DETS*

To determine the subgame perfect equilibrium of this game we proceed backward. Therefore, we solve first the firms' problem at the second stage of the game and then the national regulators' problem at the first stage.

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

3.1.1 The firms' problem

By maximizing (2) we get the firms' first order conditions w.r.t. e_i

$$\frac{\partial B_i(e_i)}{\partial e_i} - \frac{\partial N(u_i, v_i)}{\partial v_i} = 0 \tag{5}$$

and w.r.t. q_i are:

$$-p + \frac{\partial N(u_i, v_i)}{\partial v_i} = 0 \tag{6}$$

In order to achieve full compliance, from conditions (5) and (6), the monitoring efforts must be such that the following condition holds:

$$p = \frac{\partial N(u_i^F, 0)}{\partial v_i} \tag{7}$$

that is, the marginal fine corresponding to full compliance must be equal to the permits price. The above condition implicitly defines $u_i^F(p)$.

3.1.2 The regulators' problem

Regulator i chooses the monitoring effort u_i^F required to achieve full compliance and the amount of allowances to be issued to domestic firms in order to maximize:

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

that is,

$$W_i = B_i(e_i) - p(e_i - \overline{e}_i) - \psi_i(u_i^F) - D_i(e_i + e_j) \tag{8}$$

Taking the first order conditions with respect to $\overline{e}_i$, and imposing $\frac{\partial B_i(e_i)}{\partial e_i} = p$ from (5) and (6), we get:

$$\frac{\partial W_i}{\partial \overline{e}_i} = p - \frac{\partial p}{\partial \overline{e}_i}(e_i - \overline{e}_i) - \frac{\partial \psi_i(u_i^F)}{\partial u_i}\frac{\partial u_i^F}{\partial p}\frac{\partial p}{\partial \overline{e}_i} - \left(\frac{\partial D_i}{\partial e_i}\frac{\partial e_i}{\partial p} + \frac{\partial D_i}{\partial e_j}\frac{\partial e_j}{\partial p}\right)\frac{\partial p}{\partial \overline{e}_i} = 0$$

Since the equilibrium on the permits market implies $\left(\frac{\partial e_i}{\partial p} + \frac{\partial e_j}{\partial p}\right)\frac{\partial p}{\partial \overline{e}_i} = 1$ and the uniformly mixing pollutant assumption implies $\frac{\partial D_i}{\partial e_i} = \frac{\partial D_i}{\partial e_j}$, the above first order condition can therefore be rewritten as:

$$\frac{\partial W_i}{\partial \overline{e}_i} = p - \frac{\partial p}{\partial \overline{e}_i}(e_i - \overline{e}_i) - \frac{\partial \psi_i(u_i^F)}{\partial u_i}\frac{\partial u_i^F}{\partial p}\frac{\partial p}{\partial \overline{e}_i} - \frac{\partial D_i}{\partial e_i} = 0 \tag{9}$$

The corresponding first order conditions for country j are, of course:

$$\frac{\partial W_j}{\partial \overline{e}_j} = p - \frac{\partial p}{\partial \overline{e}_j}(e_j - \overline{e}_j) - \frac{\partial \psi_j(u_j^F)}{\partial u_j}\frac{\partial u_j^F}{\partial p}\frac{\partial p}{\partial \overline{e}_j} - \frac{\partial D_j}{\partial e_j} = 0 \tag{10}$$

3.1.3 The price of permits

Solving (9) with respect to $\frac{\partial p}{\partial \bar{e}_i}(e_i - \bar{e}_i)$, accounting that the equilibrium on the permits market implies $\frac{\partial p}{\partial \bar{e}_i}(e_i - \bar{e}_i) = -\frac{\partial p}{\partial \bar{e}_j}(e_j - \bar{e}_j)$ and substituting in (10) we get, after some manipulation, the following condition for the equilibrium price of permits under decentralization:

$$p_d = \frac{1}{2}\left(\frac{\partial \psi_i(u_i^F)}{\partial u_i}\frac{\partial u_i^F}{\partial p} + \frac{\partial \psi_j(u_j^F)}{\partial u_j}\frac{\partial u_j^F}{\partial p}\right)\frac{\partial p}{\partial \bar{e}} + \frac{1}{2}\left(\frac{\partial D_i}{\partial e_i} + \frac{\partial D_j}{\partial e_i}\right) \tag{11}$$

3.2 The solution of the game under the *CETS*

Also for this game we have to proceed backward and solve first the firms' problem at the second stage of the game and then the centralized regulator's problem at the first stage.

3.2.1 The firms' problem

Since the second stage of this game is the same as the second stage of the game under the *DETS*, the firms' first order conditions w.r.t. e_i and w.r.t. q_i are, again, (5) and (6) defined in section 3.1.1. The same holds for the condition implicitly defining full compliance effort, given in (7).

3.2.2 The regulator's problem

The centralized regulator chooses emission allowances to be allocated to the firms in the two countries in order to achieve full compliance and to maximize (3). Under the *CETS* we can consider any permits revenue (cost) of firm i ($i = A, B$) as an equivalent cost (revenue) of firm j ($j = A, B$, $j \neq i$). Therefore we can rewrite (3) as follows:

$$W = B_d(e_A) + B_f(e_B) - c_d(u_d^F) - c_f(u_f^F) - D_d(e_A + e_B) - D_f(e_A + e_B) \tag{12}$$

By taking the first derivative of (12) with respect to $\bar{e}_i$ ($i = A, B$) and using the same arguments as in section 3.1.2, we get:

$$\frac{\partial W}{\partial \bar{e}_i} = p - \frac{\partial c_i(u_i^F)}{\partial u_i}\frac{\partial u_i^F}{\partial p}\frac{\partial p}{\partial \bar{e}_i} - \frac{\partial c_j(u_j^F)}{\partial u_j}\frac{\partial u_j^F}{\partial p}\frac{\partial p}{\partial \bar{e}_i} - \frac{\partial D_i}{\partial e_i} - \frac{\partial D_j}{\partial e_i} = 0 \tag{13}$$

3.2.3 The price of permits

By rearranging (13) we finally get the following condition, implicitly defining the overall emissions target under the *CETS*:

$$p_c = \frac{\partial c_i(u_i^F)}{\partial u_i}\frac{\partial u_i^F}{\partial p}\frac{\partial p}{\partial \bar{e}} + \frac{\partial c_j(u_j^F)}{\partial u_j}\frac{\partial u_j^F}{\partial p}\frac{\partial p}{\partial \bar{e}} + \frac{\partial D_i}{\partial e_i} + \frac{\partial D_j}{\partial e_i} \tag{14}$$

where p_c is the equilibrium price of permits in a centralized setting.

4 Some comparative statics

In this section we derive some interesting comparative statics results, using the conditions derived so far. 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 decreases with the price of permits.*

Proof. Note that

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

and

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

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

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

■

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 [11] and, for the case of a firm facing emissions taxes, in Harford [8] the emissions' choice is independent of the probability that the firm is monitored. Strandlund and Dhanda [15], moreover, show that this independence extends also to the degree of enforcement pressure. Our very general definition of $N_i(v_i, u_i)$, however, allows us to note that the independence from the monitoring effort (that may be thought of 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 [11] and Strandlund and Dhanda [15]. 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. Given $\frac{\partial N(u_i,v_i)}{\partial u_i \partial v_i} > 0$, 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 $\frac{dp}{du_i}$ is positive. The equilibrium on the permits market implies:

$$q_A + q_B = \bar{e}$$

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

$$\frac{\partial q_A}{\partial p} dp + \frac{\partial q_A}{\partial u_A} du_A + \frac{\partial q_B}{\partial p} dp + \frac{\partial q_B}{\partial u_B} du_B = 0$$

that is,

$$\frac{dp}{du_i} = -\frac{\frac{\partial q_i}{\partial u_i}}{\frac{\partial q_A}{\partial p} + \frac{\partial q_B}{\partial p}} > 0$$

for any $i = A, B$. ■

Therefore, immediate corollaries of results 1 and 3 are that, as noted by both Malik [11] and Strandlund and Dhanda [15], 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 investigate the relationship between emission allowances and their equilibrium price. As it is standard, we get:

Result 4 *An increase in the initial endowment of permits in any country causes the equilibrium permits price to decrease.*

Proof. Again, the equilibrium on the permits market implies:

$$q_A + q_B = \bar{e}$$

and, as $du_i = 0$ for all i, comparative statics imply:

$$\left(\frac{\partial q_A}{\partial p} + \frac{\partial q_B}{\partial p} \right) dp = d\bar{e}$$

that is,

$$\frac{dp}{d\bar{e}} = \frac{1}{\frac{\partial q_A}{\partial p} + \frac{\partial q_B}{\partial p}} < 0$$

for any $i = A, B$. ■

We can use the above results to investigate the consequences of the full compliance assumption. Comparative statics imply that $\frac{\partial u_i^F(p)}{\partial p} > 0$. Combining (7) and Result 4 we get to the following Proposition:

Proposition 1 *An increase in allowances endowment in country i decreases the effort needed* both *in country i and in country j to achieve full compliance.*

Proof. Result 4 shows that $\frac{dp}{d\overline{e}} < 0$. As a consequence:

$$\frac{\partial u_i^F(p)}{\partial p}\frac{dp}{d\overline{e}} < 0$$

for any i. ■

In other words, the monitoring effort needed to achieve full compliance increases (decreases) with the equilibrium price of permits (the aggregate emission cap). This conclusion suggests the existence of a positive spillover among countries in a decentralized setting: an increase in the national cap in country i implies a decrease in permits' price and, therefore, a decrease in the enforcement effort needed to achieve full compliance in country j. The relevance of such spillover will be discussed in the following sections.

5 Environmental quality and social welfare

Comparing the first order conditions under decentralization with those arising in a centralized setting and accounting for the fact that, in equilibrium, $\frac{\partial p}{\partial \overline{e}_i}(e_i - \overline{e}_i) = -\frac{\partial p}{\partial \overline{e}_j}(e_j - \overline{e}_j)$ and that $\frac{\partial p}{\partial \overline{e}_i} = \frac{\partial p}{\partial \overline{e}_j}$ we get:

$$\frac{\partial W}{\partial \overline{e}_i} - \frac{\partial W_i}{\partial \overline{e}_i} = \left(\frac{\partial \psi_i(u_i^F)}{\partial u_i} - \frac{\partial c_i(u_i^F)}{\partial u_i}\right)\frac{\partial u_i^F}{\partial p}\frac{\partial p}{\partial \overline{e}_i} - \frac{\partial c_j(u_j^F)}{\partial u_j}\frac{\partial u_j^F}{\partial p}\frac{\partial p}{\partial \overline{e}_i} - \frac{\partial D_j}{\partial e_i} - \frac{\partial p}{\partial \overline{e}_i}(e_j - \overline{e}_j)$$

1. The term $-\frac{\partial p}{\partial \overline{e}_i}(e_j - \overline{e}_j)$ 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 $-\frac{\partial D_j}{\partial e_i}$ 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. This effect is discussed in detail by [5]. In the rest of the paper we will label such international environmental externality as a **pollution spillover.**

3. The term $\left(\frac{\partial \psi_i(u_i^F)}{\partial u_i} - \frac{\partial c_i(u_i^F)}{\partial u_i}\right) \frac{\partial u_i^F}{\partial p} \frac{\partial p}{\partial \overline{e}_i}$ identifies the consequences of any asymmetry in enforcement costs among centralized and decentralized institutional scenarios. The consequence of an asymmetry in monitoring costs will be addressed in the last part of the paper. This term disappears if no cost differential is assumed between centralized and decentralized regulators.

4. The term $-\frac{\partial c_j(u_j^F)}{\partial u_j} \frac{\partial u_j^F}{\partial p} \frac{\partial p}{\partial \overline{e}_i}$ identifies a positive spillover among countries, already explained in Proposition 1: an increase 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. We call such spillover **enforcement spillover.**

The net effect of the four spillovers is not obvious or straightforward. To gain further insights, assume now that countries are symmetric. As $u_i^F = u_j^F = u^F$, this amounts to assuming that, $\frac{\partial c_i(.)}{\partial u_i} = \frac{\partial c(.)}{\partial u_i}$ in a centralized setting and $\frac{\partial \psi_i(.)}{\partial u_i} = \frac{\partial \psi(.)}{\partial u_i}$ in a decentralized setting, for $(i = A, B)$. Further, assume that the damage function is symmetric (i.e. $D_i(.) = D_j(.) = D(.)$) and the same holds for the benefits function (i.e. $B_i(.) = B_j(.) = B(.)$). As a consequence, we can rewrite condition (14) and (11) as:

$$p = 2\frac{\partial c(u^F)}{\partial u_i} \frac{\partial u^F}{\partial p} \frac{\partial p}{\partial \overline{e}} + 2\frac{\partial D}{\partial e_i} \tag{15}$$

$$p = \frac{\partial \psi(u^F)}{\partial u_i} \frac{\partial u^F}{\partial p} \frac{\partial p}{\partial \overline{e}} + \frac{\partial D}{\partial e_i} \tag{16}$$

The following result is, then, straightforward.

Proposition 2 *If no asymmetry is introduced among countries and/or institutional settings, then the positive* ***enforcement spillover*** *is always dominated by the negative* ***pollution spillover****.*

Proof. The result follows immeditely from either (15) and (16) and the assumption of a strictly positive permits price. ■

It is not easy to get further readable insights; however, we can investigate the consequences of decentralization if no cost advantage is assumed in favour of a decentralized setting. More specifically, assume that $c(.) = \psi(.)$. We get therefore to the following:

Proposition 3 *If no asymmetry is introduced among countries and/or institutional settings, decentralization* per se *always leads to higher emissions than centralization.*

Proof. Given our additional symmetry assumptions, we can rewrite the first order conditions for the centralized and decentralized case, respectively, as follows[9]:

$$\frac{\partial B(.)}{\partial e_i}-\frac{\partial c(u^F(\overline{e}_c))}{\partial u}\frac{\partial u^F(\overline{e}_c)}{\partial p}\frac{\partial p(\overline{e}_c)}{\partial \overline{e}}-\frac{\partial D(\overline{e}_c)}{\partial e_i}=\frac{\partial D(\overline{e}_c)}{\partial e_i}+\frac{\partial c(u^F(\overline{e}_c))}{\partial u}\frac{\partial u^F(\overline{e}_c)}{\partial p}\frac{\partial p(\overline{e}_c)}{\partial \overline{e}_i} \tag{17}$$

$$\frac{\partial B(.)}{\partial e_i}-\frac{\partial c(u^F(\overline{e}_n))}{\partial u_i}\frac{\partial u^F(\overline{e}_n)}{\partial p}\frac{\partial p(\overline{e}_n)}{\partial \overline{e}_i}-\frac{\partial D(\overline{e}_n)}{\partial e_i}=0 \tag{18}$$

where the right hand side in (17) is strictly positive by Proposition 2, while in (18) we accounted for the fact that under perfect symmetry there is no trading of permits in equilibrium. As the left hand side of both (17) and (18) must be decreasing in $\overline{e}_i$ to ensure that the decentralized regulators problems are concave problems, the proof is completed. ■

The last two results have relevant consequences on the choice betrween a centralized and a decentralized setting. More specifically, in a perfectly symmetric framework, the choice of a decentralized setting cannot be supported either in terms of social welfare (which is of course higher *by definition* in a centralized setting) or under an environmental quality point of view. Further, Proposition 2 implies that, unless the permits price is driven to 0, full compliance does not alter the presence of an "aggregate" negative spillover among countries in a decentralized setting.

5.1 Asymmetry in monitoring costs

5.1.1 Model results

A symmetric setting is useful as a benchmark, and it allows to investigate all the consequences of decentralization *per se.* As we demonstrated, when countries are completely identical and there is no monitoring cost advantage favouring decentralization, the latter cannot be justified under any respect. So why should we choose decentralization in the first place? As already outlined in the introduction, the answer to this question might depend on the relative ease in monitoring and enforcement that might characterize countries belonging to an Economic Union (or to a federation of States). In order to get readable insights we need, however, to keep the symmetric countries assumption and to introduce specific functional forms for costs, benefits and social welfare functions.

We assume for country i ($i = A, B$) the following specific shapes for the expected benefits and expected fine functions:

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

[9] $\overline{e}_c$ and $\overline{e}_n$ are, respectively, aggregate environmental standards under centralization and decentralization.

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 F is a positive constant representing the unit fine for noncompliance. The quadratic term is related to the likely obligation of regulated firms to abate excess pollution once found uncompliant.

The damage function for each country is quadratic and implies (coherently with the assumption of symmetry among countries) that marginal damage is the same in country A and B for any given amount of total emissions:

$$D(.) = \frac{1}{2}(\overline{e}_A + \overline{e}_B)^2$$

Finally, the monitoring cost function is assumed to be linear in monitoring effort, and is the only source of asymmetry among institutional settings. More specifically, under centralization:

$$c(.) = \lambda u,$$

while in a decentralized setting:

$$\psi(.) = \lambda_d u.$$

Using the above functional forms and solving the firms' and regulators' maximization problem we get the following values for aggregate environmental targets, equilibrium price of permits, monitoring needed to achieve full compliance and social welfare (notice that, as before, subscripts c label values obtained in a centralized setting, while d labels decentralization results[10]:

	Centralized	Decentralized
Emissions	$\overline{e}_c = \frac{1}{5F}\left(2F + 2\lambda\right)$	$\overline{e}_d = \frac{1}{3F}\left(2F + \lambda_d\right)$
Price	$p_c = \frac{1}{5F}\left(4F - \lambda\right)$	$p_d = \frac{1}{6F}\left(4F - \lambda_d\right)$
Monitoring	$u_c = \frac{1}{5F^2}\left(4F - \lambda\right)$	$u_d = \frac{1}{6F^2}\left(4F - \lambda_d\right)$
Welfare	$W_c = \frac{1}{5F^2}\left(F^2 - 8F\lambda + \lambda^2\right)$	$W_d = \frac{1}{36F^2}\left(4F^2 - 56F\lambda_d + 7\lambda_d^2\right)$

5.1.2 Comparisons

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

$$\lambda = \eta\lambda_d$$

where

[10] We do not go into the details of the numerical calculations, that are coherent with the implicit calculations performed in the preceeding sections. All the details are available from the authors upon request. Further, in order to guarantee that price of permits is not driven to 0, we must assume that $\lambda < 4F$.

- 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 regulators.

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

$$\Delta\overline{e} = \overline{e}_d - \overline{e}_c = \frac{1}{15F}\left(5\lambda_d + 4F - 6\lambda_d\eta\right)$$

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

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

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

We can therefore state the following Proposition:

Proposition 4 *A sufficiently high cost differential in favor of the decentralized regulators 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* $\Delta\overline{e} > 0$
- if $\eta > \eta_e$ then $\Delta\overline{e} < 0$.

The intuition for this result is as follows; when the cost differential is very high then the "differential" incentive of the centralized regulator 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:

$$\Delta W = W_d - W_c = \frac{1}{180}\frac{35\lambda_d^2 + 288\eta\lambda_d F - 16F^2 - 280F\lambda_d - 36\eta^2\lambda_d^2}{F^2}.$$

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

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

This leads us to the following Proposition.

Proposition 5 *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* $\eta < \eta_W^1$

- $\Delta W > 0$ *for* $\eta_W^1 < \eta < \frac{4F}{\lambda_d}$

Results in propositions 4 and 5 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 $\eta_E < \eta < \frac{4F}{\lambda_d}$

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

Notice, further, that λ_d plays an important role in determining all the above threshold values. Taking the first derivative of η_e and η_W^1 with respect to λ_d we get:

$$\frac{\partial \eta_e}{\partial \lambda_n} = -\frac{2F}{3\lambda_d^2} < 0$$

$$\frac{\partial \eta_W^1}{\partial \lambda_n} = \left(\frac{2}{3}\sqrt{35} - 4\right)\frac{F}{\lambda_d^2} < 0$$

As a consequence, an increase in λ_d reduces the threshold above which emissions are higher in a centralized settingas well as the threshold above which social welfare is higher in a decentralized setting.

Results obtained are coherent and add to those gained in section 4. A number of lessons can be learned from our analysis:

- if no asymmetry among countries and/or institutional settings is introduced, decentralization cannot be justified under any respect (social welfare and/or environmental quality);

- the introduction of a monitoring cost differential in favour of decentralized regulators is a necessary but not sufficient condition to provide support to a decentralized ETS. Decentralization is only justifiable if such cost differential is sufficiently high as to provide the centralized regulator with relatively strong incentives to issue permits in order to drive the price (as well as the monitoring effort) down.

- An increase in decentralized (and, given η, centralized) unit monitoring costs implies all the thresholds defined above to shift down, leading to an even less favourable situation for centralization. This is reasonable: when $\eta > 1$ the incentive for the central regulator to issue permits in order to drive full compliance monitoring down grows more rapidly than the same incentive in a decentralized setting.

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 regulators, 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 welfare analysis 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 federal level we 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 [5].

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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