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RESUMEN

Un sistema de permisos negociables, en el contexto estándar, resulta ser efectivo para lograr los objetivos de política ambiental con respecto a reducción de la contaminación con el mínimo coste. Este resultado se pone en cuestión en el caso de que dicho sistema se utilice en un estado federal con estados individuales que tienen poder discrecional en cuanto a la política ambiental y si la contaminación es transfronteriza entre los estados. Este trabajo analiza las posibilidades de la autoridad central para determinar la efectividad del sistema bajo distintos entornos institucionales, por medio de la asignación inicial de permisos.

Palabras clave: permisos negociables, restricciones al comercio, federalismo fiscal.

ABSTRACT

A system of tradable permits in the standard setting is effective in attaining the policy objective with regard to pollution reduction at the least cost. This outcome is challenged in case of a tradable permit system in a federal state with individual states having discretionary power regarding environmental policy and where pollution is transboundary across states. This paper explores the opportunities of the central authority to influence the effectiveness of the system, under different institutional arrangements, through the initial allocation of permits

Keywords: tradable permits, trade bans, fiscal federalism.
JEL Classification: H21, H23, Q00

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1. Introduction

A tradable emissions permit (TEP) system is typically associated with the twin aim of attaining the centrally set economy-wide level of emissions, and achieving cost efficiency. All the (federal) government has to do, is to determine the desired pollution level, and to distribute the total number of permits associated with the optimal pollution level among those firms, that emit a pollutant in the production process. The profit-maximizing firms have the possibility to reduce emissions by means of an abatement technology or by buying permits instead. Given the initial allocation of permits to the firms, in competitive equilibrium the market price for permits equals marginal abatement costs, which are therefore equal across firms implying that total abatement costs are minimised. Furthermore all permits will be used in equilibrium, implying that the goal with respect to pollution is exactly met. The two objectives of minimal abatement cost and attaining the desired level of pollution are achieved whatever the initial allocation of permits. Allocating permits is, therefore, in the standard TEP systems inessential to reaching the objectives.

However, in order for these nice properties to hold several conditions need to be satisfied. The main problems that can arise within this setting are that the assumption of competitiveness is not satisfied, and that lower-level authorities such as states in the US or member countries in the EU might interfere with the permits market. Regarding the former, cost-effectiveness is jeopardised when one or a few firms have market power on the permits market (Hahn, 1984, and Kolstad, 2000 pp. 167-170). Regarding the latter, the states' own objectives in environmental policy might prevent the achievement of the federally set standards.

Nowadays TEP systems are in place for several pollutants at national levels within Europe and the US, and a TEP system is currently on the agenda for the entire EU for greenhouse gas emissions. In the US there already exists a nation wide TEP system for sulphur-dioxide. For an evaluation of SO_2 allowance trading program see Schmalensee *et al*., 1998 and Stavins, 1998. These federal systems will operate in the way described above, if the individual states just pursue profit maximisation on the part of their (polluting) firms. Obviously, their objective is much broader, including other welfare aspects such as consumer surplus. As is well-known, welfare maximization at the state level does not have to coincide with welfare maximization at the nation-wide level. A state fails to take account of the externalities it imposes on the residents of other states, while on the other hand, states are not able to correct for externalities other states are imposing upon their residents. The tax-competition literature concludes in such cases that the federal government should correct inefficient local policies by centralizing the decision power, or by introducing appropriate corrective grants (see Wilson, 1999, for an overview of this literature).

In the context of a TEP-system states can interfere with the objectives of the federal government by setting their own taxes on firms within their own states, or by having their own regulations on the trade of permits by companies within the state borders. This can come down to imposing trade bans on the sale of permits. Under the latter type of intervention states withdraw a certain number of the allocated permits from the market. This has been the case in the US, where the state of New York has prevented their electricity companies from selling permits to companies in Southern and Midwestern States, by imposing fines on utilities making such sales.

State intervention can be motivated by the existence of asymmetric transboundary pollution, causing so-called hot spots where a disproportionally large part of the pollution is emitted. In general the resulting uniform market price for permits does not correspond with first-best in that case. Spatial aspects are in play. In particular, asymmetric pollution spill-overs will call for differing levels of environmental quality and differing admissible levels of pollution across states. Such requirements for efficiency, however, seem to be impossible to reconcile with a system of a laissez-faire TEP system where the final allocation of emission activities is independent of the initial allocation of permits. It is known from the literature, see e.g., Tietenberg (2003) and Hanley *et al*. (1997), that with non-uniformly mixed pollutants abatement cost minimization calls for an ambient permit system, where permits refer not to the right to emit but to the right to deposit at certain receptor points. However, in practice at federal levels this is not the way how pollution is dealt with.

As shown by Santore, Robison and Klein (2001), if asymmetric pollution spillovers occur, in a TEP system where states intervene by imposing taxes on the polluting activities within their state, the outcome of the TEP market will generally not be *permits-constrained* Pareto efficient, meaning that a central authority can improve welfare in one state without decreasing it in another state, *given* the total number of permits issued. Moreover, given that states use their own taxes to steer the decisions of the companies within their own border, it follows that whatever the final allocation, cost efficient abatement will only occur if all states happen to impose identical tax rates. On the other hand, if a Pareto efficient outcome in the presence of asymmetric pollution were to occur, it will not be characterized by cost efficient abatement. The intuition for this result is that minimizing pollution abatement costs will in general not provide the necessary corrections for asymmetric pollution spillovers.

The present paper addresses the case where the central government has some discretion regarding the allocation of permits to states. Therefore, contrary to Santore *et al*. we consider the case where the number of permits and its distribution is not given but where they are policy variables for the central government. The main question in this context is then under what circumstances a combination of centrally set pollution limits and decentralised intervention by means of taxes and/or trade bans on emission activities can lead to a first-best solution. The policy relevance of this is obvious. In the design of a TEP at the federal level, the policy followed by the member states should be taken into account. In this sense the issue directly touches on crucial aspects of fiscal federalism. In particular, questions like which government level should set environmental standards, and which instruments federal and lower-level governments have and/or should be allowed to use in order to meet the stated objectives are at stake. When transboundary pollution occurs, the "natural response is to invoke central intervention of some kind", Oates (2003, p. 4). But, as he immediately notes, uniform regulations are unlikely to lead to first-best efficiency. He prefers regional cooperation as potentially offering a resolution of jurisdictional spillover effects. What we will show, however, is that a TEP-system in a federation where the federal government sets the nation-wide pollution level and decides on the distribution of permits, while the states decide on the taxes they impose on their local companies, can lead to first-best.

The analysis takes place in a model that resembles the model used by Santore *et al.*, but there are two important differences, apart from the endogeneity of the permit distribution. We deviate from Santore *et al.* by assuming that one nation-wide electricity market exists. Given such a market, states cannot compensate restraints on the taxes that they can set, by inflicting distortions in the local electricity market. Moreover, as in the context of transboundary pollution cost-efficient abatement is not an issue anyhow, as we argued above, and in order to focus on distributional issues as much as possible, we also abstract from abatement.

The main outcomes of the paper can be sketched as follows. If states impose local taxes, firms' production and polluting behaviour will be affected on the margin, and the federal government can employ this knowledge by distributing the permits across states such that the first-best allocation of production and pollution is attained. This result will also hold if states cannot give a subsidy to their local polluting plants. If states use trade bans to affect the emission of pollution in their state, the first-best allocation can in general not be attained by manipulating the distribution of permits. Here the intuition is that a state, by withdrawing permits from use in their state, imposes a kind of a lump sum tax on the local firms. This does not affect the firm on the margin, but via the income effect it engenders on local firms, the nation-wide electricity price will be affected. Obviously, as this price increase is uniform across all states, the use of local trade bans will not enable the federal government to correct asymmetric spillovers by manipulating the distribution of the permits over the states.

In the next section we introduce the model and determine the first-best optimum. Section 3 deals with the case where individual states can set pollution taxes on their firms, whereas section 4 also allows for trade bans. Section 5 present some numerical exercises that illustrate the results from sections 3 and 4 (in a somewhat more general model). Finally, section 6 concludes.

2. The model, first-best optimum and laissez-faire

In this section we present the model and derive the conditions for a first-best optimum. We also show that a standard TEP will not achieve the first-best optimum.

The formal model reads as follows. There are n $(n > 1)$ states. Each state i produces electricity, y_i, with a technology giving rise to a production cost function C_i that is continuous, increasing and strictly convex. There is interstate trade of electricity but no net exports are allowed. Production brings along emissions in a one to one way[2]: $e_i = y_i$. Emissions of a state do not coincide in principle with deposits in that state, due to the transboundary character of the pollutant. Deposits within state i are given by d_i, which are a function of emissions. Agents in each state have preferences defined on the consumption of electricity (z_i), deposits in their own state, and money (capturing all other commodities). It is assumed that consumers are identical within as well as across states. Moreover, the populations in all states are identical. Social welfare in a state is then given by $W_i(z_i, m_i, d_i)$. Here m_i denotes money holdings, accruing to the state from the exports of electricity minus production costs and expenditures on electricity: $m_i = py_i - C_i(y_i) - pz_i$. At no cost one could include an exogenous component. Welfare is decreasing in deposits and increasing in the other arguments. It is assumed that welfare is additively separable in the three arguments $W_i(z_i, m_i, d_i) = U_i(z_i) + m_i - D_i(y)$, where U_i denotes utility from electricity consumption and D_i is the damage caused by emissions, depending on emissions generated in all states ($y = (y_1, y_2, ..., y_n)$).

The first-best optimum from the point of view of the federal government is the solution of the following optimisation problem:

$$\text{Max} \sum_{i=1}^{n} [U_i(z_i) - C_i(y_i) - D_i(y)]$$

subject to

[2] This assumption is relaxed in the numerical exercises performed in section 5.

(2.1) $$\sum_{i=1}^{n} z_i = \sum_{i=1}^{n} y_i$$

Note that in the federal government's objective function the terms $py_i - pz_i$ are absent because their aggregate over the states equals zero. The Lagrangian reads:

$$\sum_{i=1}^{n}[U_i(z_i) - C_i(y_i) - D_i(y)] + \kappa\sum_{i=1}^{n}[y_i - z_i]$$

Assume that there exists an interior solution. Then the following conditions hold

(2.2) $$U_i^{'}(z_i) = \kappa,\ \ i = 1,2,...,n$$

(2.3) $$\kappa = C_i^{'}(y_i) + \sum_{j=1}^{n} D_{ji}(y)\ ,\ i = 1,2,...,n$$

where D_{ji} denotes the partial derivative of D_j with respect to the $i-th$ element. The interpretation of these conditions is as follows. Equations (2.2) and (2.3) indicate that marginal utility of electricity in each state should equal marginal cost, consisting of production costs and the costs of emissions, inflicted on all states. In the sequel the values in the first-best optimum will be denoted by hats. The system of equations (2.2) and (2.3) yields the optimal amount of emissions for each individual state $\hat{e}_i = \hat{y}_i$ for $= 1,2,...,n.$ The first-best optimum will therefore be implemented by allocating this amount of permits to each individual state and by not allowing trade in the allocation.

However, this is not the way a TEP system works. Instead, in a standard TEP system the federal government issues tradable permits, and allows for trade in these permits. As a necessary, but as is shown below by no means sufficient, condition to reach the first-best optimum the federal government should issue a number of permits amounting in total to the first-best optimum number, denoted by $\hat{x}.$ The beneficiaries are the electricity companies, or the states who distribute them to the electricity companies without any restriction on how to use the permits. The electricity companies take the price τ on the federal permit market as given. This TEP regime will be called *laissez-faire*. It is well known that it will in general not generate the first-best optimum, as will be shown below. Consumer demand for electricity is given by

(2.4) $U_i'(z_i) = p$

where p is the market price for electricity. Electricity supply of a firm confronted with a permit price τ follows from the maximisation of its profits

$$py_i - C_i(y_i) - \tau y_i$$

Hence

(2.5) $p = C_i'(y_i) + \tau$

Therefore, when taking (2.2) and (2.3) into account one observes that a necessary condition for achieving the first-best solution is:

(2.6) $\tau = \sum_{j=1}^{n} D_{ji}(\hat{y})$ for all i

It is clearly the case that this condition is unlikely to be satisfied in the laissez-faire equilibrium. Since the federal government issues the first-best amount of permits, it follows however that $p = \hat{\kappa}$. This is due to the assumption that emissions are proportional with production with factor of proportionality equal to unity, which implies that total emissions equal total electricity production, which in its turn equals aggregate electricity demand. Hence, the assumption allows for a precise identification of the reason why the first-best optimum is not realised. The reason is not a suboptimal level of electricity production but it comes from an inefficient allocation of production over the individual electricity companies, that do not take the spatial aspects of emissions into account.

3. Emission taxes by states

In this section we consider the distribution of permits across states when the federal government takes account of tax setting behaviour by states. Each individual state maximises the welfare of its citizens taking the behaviour of consumers and producers as given. Consumer behaviour is given by (2.4). With regard to the electricity firm, each state i

imposes an emission tax denoted φ_i. This tax is not bound to be positive, so that it can actually be a subsidy on emissions. In the present section we only consider taxes as a policy instrument at the state level; trade bans will be discussed in the next section. Under these assumptions profit maximisation on the part of the firm leads to

$$p = C_i^{'}(y_i) + \tau + \varphi_i \tag{3.1}$$

From (2.4) and (3.1) demand and supply of electricity can be derived as depending on the electricity price, the permit price and the state pollution tax: $z_i(p)$ and $y_i(p, \tau + \varphi_i)$, respectively. The social welfare function of state i consists of consumer surplus from electricity consumption plus the revenues from the emission tax which are transferred to the consumer in a lump sum fashion, the producer surplus from electricity production, including revenues from the sale of permits, minus local emission taxes, and, finally, damage caused by emissions. Since emission taxes cancel out, the objective of the state is to maximise:

$$U_i(z_i) - pz_i + py_i - C_i(y_i) + \tau[x_i - y_i] - D_i(y)$$

If the individual state would take the permit price as given, we would be back in the previous case of laissez-faire. Instead it is now assumed that the states play a Nash game against each other: each state takes the emission taxes by all other states as given, but in the optimisation it takes account of the impact its own emission tax has on pollution of each other state through the equilibrium on the permits market, and, therefore, on the permits price, i.e. $\tau = \tau(\varphi)$, where $\varphi = (\varphi_1, \varphi_2, ..., \varphi_n)$. Indeed if the federal government issues a total amount x of permits, then in equilibrium $\sum_{i=1}^{n} y_i(p, \tau + \varphi_i) = x$, where, for all i, $y_i(p, \tau + \varphi_i)$ follows from (3.1). Moreover, since $\sum_{i=1}^{n} z_i = \sum_{i=1}^{n} y_i = x$ the equilibrium electricity price follows from (2.4) as a function of x. In the model the market price of electricity is therefore beyond the control of individual states, because it is fully determined by the amount of permits issued, through (2.4). So, demand for electricity is exogenous. This implies that, as $\tau = \tau(\varphi)$, for a given amount of total permits, we can write $y_i = y_i(\varphi)$ $(i = 1,2,...,n)$. In the Nash equilibrium we then have

$$(3.2) \qquad (p - C_i'(y_i) - \tau)\frac{\partial y_i(\varphi)}{\partial \varphi_i} + (x_i - y_i)\frac{\partial \tau(\varphi)}{\partial \varphi_i} - \sum_{j=1}^{n} D_{ij}(y)\frac{\partial y_j(\varphi)}{\partial \varphi_i} = 0\,,$$

for $i = 1,2,...,n$. The leading principle of the planner at the state level is to equalise marginal cost and marginal benefits. These are represented in the three terms on the left-hand side of (3.2). An increase in the tax rate will in first instance decrease production. Revenues decrease but production costs and expenditures on permits decrease as well. Also the permits price will change. Given fixed emission taxes set by other states less demand from the home firm induces a decrease of permits price, which is beneficial if $x_i < y_i$ and not beneficial if $x_i > y_i$. Finally, the effect on pollution in the home country as a consequence of the reaction of other states has to be taken into account.

It is clear from (3.2) that, contrary to the standard TEP system, the equilibrium is determined by the distribution of the initial allocation, which is a result that is well known in the literature (see e.g. Santore *et al.* (2001)). However, the following proposition demonstrates that the first-best solution can be attained:

Proposition 1. Given that states set local taxes according to (3.2), generally an initial allocation of permits exists that generates the first-best-outcome.

Proof.
We can restrict ourselves to an allocation where the federal government issues the first-best total amount of permits. Then it follows that the equilibrium price p coincides with the first-best marginal utility $\hat{\kappa}$. That implies that each state will consume the optimal amount of electricity. Next insert the first-best y_i's in (3.2) and evaluate all partial derivatives in this expression at the first-best optimum, meaning that we consider $\hat{\varphi}$ such that $y_i(\hat{\varphi}) = \hat{y}_i$ for $i = 1,2,...,n.$ Then we end up with $n+1$ equations (namely (3.2) and $\sum_{i=1}^{n} x_i = \hat{x}$) with $n+1$ unknowns (namely τ and x_i $(i = 1,2,...,n)$). Therefore, under standard regularity conditions, the first-best optimum can be realised by a proper initial distribution of tradable permits.□

The proof of the proposition does not make use of our assumption that emissions are uniformly proportional to production $e_i = y_i$ (for all i). It also holds in a more general case where this assumption is not made. The only thing that is needed is that for all i, $y_i(\hat{\varphi}) = \hat{y}_i$ has a solution for $\hat{\varphi}$.

It is not true that any distribution will do the job. As an illustration we consider two very simple examples.

Example 1.

There are three states with identical cost functions: $C_i(y_i) = \frac{1}{2} y_i^2$ ($i = 1,2,3$). States 1 and 2 experience no damage from pollution. State 3 is affected by state 1 only: $D_3(y_1, y_2, y_3) = \frac{1}{2} y_1^2$. Utility from electricity consumption is logarithmic: $U_i(z_i) = \ln z_i$ ($i = 1,2,3$). In the first-best optimum we have $z_i^2 = \frac{5}{6}$ for all i, $y_1^2 = \frac{3}{10}$, $y_2^2 = \frac{6}{5}$, $y_3^2 = \frac{6}{5}$. Individual profit maximisation by firms gives rise to $y_i = p - \tau - \varphi_i$ ($i = 1,2,3$). Summing and taking into account that $\sum y_i = \hat{x}$, leads to $\tau = -\frac{1}{3}(\varphi_1 + \varphi_2 + \varphi_3) + p - \frac{1}{3}\hat{x}$. Also $3y_i = -2\varphi_i + \sum_{j \neq i} \varphi_j + \frac{1}{3}x$. From state-wise welfare optimisation it follows that $2(p - y_1 - \tau) = y_1 - x_1$, $2(p - y_2 - \tau) = y_2 - x_2$ and $2(p - y_3 - \tau) = y_3 - x_3 - y_1$. Hence $x_1 = 0, x_2 = \frac{3}{2}p, x_3 = p, \tau = \frac{1}{4}p$, with $p = \sqrt{\frac{6}{5}}$. So, the polluting state should be forced to buy all the permits it needs, which makes sense. Compared to the first-best optimum state 1 loses, state 2 is indifferent and state 3 wins in the Nash equilibrium. So, the new allocation does not generate a Pareto improvement. Also note that states 2 and 3 subsidise emissions from their electricity plants.

Example 2.

There are two states, with $C_i(y_i) = \frac{1}{2}\gamma_i y_i^2$ with $\gamma_i > 0$ ($i = 1,2$). Damages are given by $D_1(y_1, y_2) = \frac{1}{2}t_{21}y_2^2$, $D_2(y_1, y_2) = \frac{1}{2}t_{12}y_1^2$. So, states do not pollute within their own country: all pollution is exported. We will not perform all the calculations here, but the result is now that it is optimal to assign permits to the countries according to their first-best emissions.

As the example illustrates proposition 1 does not imply that each individual state will attain the welfare corresponding to the first-best outcome. So, the new allocation does not generate a Pareto improvement compared to the first-best outcome: the new allocation may be worse for some individual states and better for some others. The claim is that total welfare over the states is equal to total first-best welfare. Indeed individual states can lose, which may be remedied with lump sum transfers between states.

It is worthwhile to dwell for a moment on the related work by Santore *et al.* (2001). The differences in modelling boil down to the following. In their model there is an exogenously given income level, and electricity production is determined by the individual states. Electricity is a non-tradable. Moreover, they do not allow for emission subsidies. We assume a nation-wide competitive electricity market. Unlike in the Santore *et al.* model, in our model states are not able to impose distortions in the electricity market, in case the optimal tax rate might not be feasible for institutional reasons. Santore *et al.* claim that for any given distribution of permits, there exists a Pareto-improving allocation of consumption and emissions. This means that with total initially given exogenous income, electricity consumption and emissions can be reallocated such that for all states involved welfare is not decreased and for one state welfare is increased. The generality of the claim is refuted in our model where there exists a permit allocation that is Pareto-efficient, namely the allocation that generates the first-best outcome. The point is simply that in our model we allow the federal government to take account of states' behaviour. By employing the mechanisms that determine the state taxes the government can indirectly steer production values to their first-best values. So, we conclude that, although they employ a somewhat different model, their claim that Nash equilibrium with permits trading is generally not (permits constrained) Pareto-efficient, only holds with a non-optimal initial distribution of permits. If the federal government is free in making the distribution a Pareto efficient allocation can be realised. Second, their restriction to nonnegative emission taxes creates a distortion that may prevent an optimal allocation: in particular when the damage caused by home firms is low it might be welfare improving to subsidise emissions. We will come back to this issue in section 5.

4. Emission taxes and trade bans

We next consider policy scenarios where states set the emission tax/subsidy and may withhold a certain number of permits, that cannot be traded by their firms. The latter quantity is denoted by u_i, unused permits, for state i $(i = 1,2,...,n)$. Hence

(4.1) $$x_i = y_i + v_i + u_i$$

where v_i is the amount of permit trades. Clearly, additional restrictions have to be imposed:

(4.2) $u_i \geq 0$ and $x_i - v_i - u_i = y_i \geq 0$.

In a Nash equilibrium a state takes the strategy of all other states as given and chooses an optimal emissions tax and an optimal trade ban. The state takes into account that a change in its policy has an impact on the permit price τ.

We maintain the assumption that each individual firm is small on the electricity market, so that no state can manipulate the electricity price. Consequently the price argument is suppressed in the demand and supply functions. In the case without trade bans total emissions in equilibrium are equal to total production, which equals aggregate demand. Hence the equilibrium permits price is given as soon as the total amount of permits is known. In the present situation this no longer holds since not all emission permits have to be used. Therefore the combined assumption of perfect competition on the electricity market and imperfect competition on the permit market is less straightforward than in the previous section.

Since $z_i = z_i(p)$ and p is given, the problem that country i $(i = 1,2,...,n)$ is facing is to maximise

(4.3) $$py_i(\tau + \varphi_i) - C_i(y_i(\tau + \varphi_i)) + \tau[x_i - y_i(\tau + \varphi_i)) - u_i] - D_i(y)$$

subject to

(4.4) $$\sum_{j=1}^{n}[y_j(\tau + \varphi_j)) + u_j - x_j] = 0$$

(4.5) $$u_i \geq 0$$

The Lagrangian reads

$$L = py_i(\tau + \varphi_i) - C_i(y_i(\tau + \varphi_i)) + \tau[x_i - y_i(\tau + \varphi_i) - u_i] - D_i(y)$$

$$+ \vartheta_i \sum_{j=1}^{n}[y_j(\tau + \varphi_j) + u_j - x_j] + \psi_i u_i$$

We arrive at the following necessary conditions for state i:

(4.6) $$\frac{\partial L}{\partial \varphi_i} = [p - C_i^{'} - \tau - D_{ii} + \vartheta_i]\frac{\partial y_i}{\partial \varphi_i} = 0$$

(4.7) $$\frac{\partial L}{\partial u_i} = -\tau + \vartheta_i + \psi_i = 0,\ \psi_i u_i = 0,\ \psi_i \geq 0$$

(4.8) $$\frac{\partial L}{\partial \tau} = [p - C_i^{'} - \tau]\frac{\partial y_i}{\partial \tau} + [x_i - y_i - u_i] - \sum_{j=1}^{n}[D_{ij} - \vartheta_i]\frac{\partial y_j}{\partial \tau} = 0$$

The interpretation of these equations is straightforward. Consider (4.6) first. An increase in the emission tax rate φ_i in state i decreases production and emissions. The marginal costs of lower production are $p - C_i^{'}$. Fewer emissions imply that fewer permits have to be bought and that there is a direct beneficial effect on local pollution. Finally, for given u_i, there will be more emissions, elsewhere in the economy by other states, which bears a cost ϑ_i, indicating the cost perceived by state i of increasing the endowment of permits at the federal level.

The interpretation of (4.8) is as follows. An increase in the permits price τ has multiple effects as well. It has the same local effects as an increase in the emissions tax rate described above (note that the partial derivatives of production with respect to emission tax and permit price are identical). But there are three additional effects. First, the revenues from selling permits are increased. Second, a higher permit price decreases emissions in the other states, which is beneficial to the local pollution in state i. Third, there occurs a decrease in emissions in the other states, which has a shadow price equal to ϑ_i.

Finally, if the state under consideration leaves some permits unused $(u_i > 0)$ then for the state the opportunity costs of a permit (ϑ_i) is just the permit price. However, when the state uses all its permits for selling them, the permit price must be at least as high as the opportunity costs. This is covered in (4.7).

Unlike the case where states employ taxes, trade bans cannot be manipulated by the federal government to steer production activities to the first-best solution. On the contrary, if states use both taxes and trade bans as instruments to regulate their firms' behaviour, the federal government will allocate the permits to the states such that states do not impose trade bans.

Proposition 2. Given that states set local taxes and trade bans according to (4.5)-(4.7), the allocation of permits generating the first-best-outcome will be one where states do not impose trade bans.

Proof.

Assume that at least one state i has a positive trade ban, $u_i > 0$. Then, we learn from equations (4.6), (4.7) and firm behaviour, i.e. $C_i^{'} = p - \tau - \varphi_i$, that the optimal state tax equals $\varphi_i = D_{ii} - \tau$. It then follows that $C_i^{'} = p - \tau - \varphi_i = U_i^{'}(z_i) - D_{ii}$, where the first-order condition for utility maximization has been inserted. Comparing this to the first-best solution (2.2.) and (2.3), we find that a positive trade ban can only be associated with the first-best if $D_{ii} = \sum_j D_{ji}$ which can only hold by co-incidence.□

Thus, the existence of positive trade bans implies that the federal government does not have instruments to reach the first-best solution. The problem here is that, contrary to local taxes, trade bans do not affect firm behaviour at the margin, and so by choosing the distribution of permits the government is not able to steer production. Or, in other words, the government is only able to affect firms' behaviour via the local taxes. In the case of the co-existence of local taxes and trade bans, however, local taxes only take care of the internal pollution as reflected by $\varphi_i = D_{ii} - \tau$. As a result, production in state i does not depend on the number of permits, but only on domestic pollution relative to the permit price. The transboundary pollution is corrected by the state by the imposition of the trade ban, as described by equation (4.8). The trade ban, obviously, depends on the number of permits allocated to state i. But, if the federal government manipulates the allocation of the permits, it affects the permits price (via the number of trade bans). A change in the permits price, however, has a uniform effect on all states and thus is not suitable to correct the asymmetric pollution effects.

It is easy to see that in case the states do not impose taxes, but only rely on trade bans for correcting the externalities, a first-best solution cannot be reached as well. Instead of giving a formal proof, we present an example that gives the basic intuition for this result.

Example 3:

Suppose the federation consists of two states, where the firms have cost functions with $C_i(y_i) = \frac{1}{2}\gamma_i y_i^2$ with $\gamma_i > 0$ $(i = 1,2)$. The damage functions are $D_1(y) = \frac{1}{2} t_{11} y_1^2 + \frac{1}{2} t_{21} y_2^2$ and $D_2(y) = \frac{1}{2} t_{12} y_1^2 + \frac{1}{2} t_{22} y_2^2$, respectively. If the states do not use local taxes, profit maximisation by the firms implies $\gamma_1 y_1 = \gamma_2 y_2 = p - \tau$. Obviously, firm behaviour does not directly depend on the (only) instrument used by the state, i.e. the trade ban. Trade bans only affect firm behaviour indirectly through the effect on the permits price. Maximisation of local welfare in state i implies that the optimal trade ban should obey: $u_i = x_i - y_i - \sum_{j=1}^{2} D_{ij} \frac{\partial y_j}{\partial \tau}$. From $y_1 + y_2 = x - u_1 - u_2$ it follows that $\gamma_1 y_1 = \gamma_2 y_2 = \frac{\gamma_1 \gamma_2}{\gamma_1 + \gamma_2}(x - u_1 - u_2)$. The optimal employment of trade bans by both states implies a fixed proportion y_1 / y_2 that in general will not coincide with the proportion y_1 / y_2 that is prescribed by the first-best solution. Suppose that only one state has a trade ban, let us say $u_1 > 0$ and $u_2 = 0$. Then, both y_1 and y_2 appear to be functions of x_2 only (and so not a function of x_1) which implies that not both y_1 and y_2 can be placed on their first-best values, and, moreover, leaves x_1 undetermined.

Proposition 2 does not claim that trade bans are individually irrational at any initial distribution of permits. In the next section we will provide examples where for some states it is optimal to impose a trade ban, if the initial allocation of permits is suboptimal.

5. A numerical example

In this section we study a numerical example with three states to illustrate the results obtained above and to gain some additional insight into the working of the model under slightly more general conditions. In particular it will be assumed that the emissions factors may vary over the firms: $e_i = \alpha_i y_i$ $(i = 1,2,3)$. Utility from electricity consumption is logarithmic, the production cost function is quadratic and damage is also quadratic with the transport coefficients given by t_{ij}: the fraction of emissions in state i that is deposited in state j.

Social welfare of state i is

$$W_i = \ln z_i) - pz_i + py_i - \tfrac{1}{2}\gamma_i y_i^2 + \tau[x_i - y_i] - \tfrac{1}{2}\sum_j t_{ji} e_j^2$$

In the sequel the following numerical values will be used.

$$\alpha = (0.1,\ \ 0.2,\ 0.15),\ \gamma = (0.2,\ 0.1,\ 0.15)\ ,\ t_{ij} = \begin{pmatrix} 0.4 & 0.0 & 0.1 \\ 0.8 & 0.1 & 0.1 \\ 0.7 & 0.0 & 0.0 \end{pmatrix}$$

So, state 1 produces with a relatively clean technology, with a low amount of pollution attached to production. Moreover, each unit of pollution leads to low levels of transboundary pollution. The spillovers in the example are asymmetric: emissions from all states lead to a relatively large disutility effect in state 1, and cause minor damage in state 2 and state 3. State 2 is the big polluter, but also has low production costs.

Given these specifications we calculate the first-best solutions, the laissez-faire permits-market equilibrium and the allocation of permits leading to the first-best welfare levels. The results of this exercise are listed in Table 1.

Column 1 describes the first-best solutions calculated with equations (2.2) and (2.3). Optimal pollution is distributed in a rather uneven fashion. In particular, it appears that state 1 does not emit much. The marginal welfare gain of containing emissions in state 1 is dominated by the production loss that would occur if, especially, state 2 pollutes less.

Column 2 gives the results for a laissez-faire permits market, with the permits allocated to the individual states according to their first-best emissions, i.e. $x_1 = 0.1944,\ x_2 = 0.5865,\ x_3 = 0.3386$. As expected, total welfare is lower than first-best welfare in this case, even though the allocated permits are fixed at their first-best level. In the final allocation both states 1 and 3 are selling part of their permits to state 2, the most polluting state with the low marginal production costs, against a high permits price which leaves state 2 with relatively low welfare.

Column 3 provides an example of a permit distribution that generates the first-best total welfare, in the case where positive and negative emission taxes are allowed. In equilibrium production of electricity in each state is at its first-best level and also the deposits of pollutants are first-best, but that does not mean that the distribution of social welfare is the same as in the first-best optimum. In terms of welfare only state 3 benefits, because that state receives more permits than it needs according to the first-best optimum. The other two states receive less permits. This leads to lower welfare for state 1 than in the first-best solution. Notice that state 1 in this case subsidises within-state pollution, $\varphi_1 < 0$, in order to correct for the pollution flowing in from the other states. The subsidy enhances permits demand by the domestic firm, thereby reducing the use of permits and hence emissions by the other two states. However, as it gets less permits than its own pollution ($x_1 = 0.1846 < e_1 = 0.1944$), the net result of this will be that the firm in the state has to pay a higher price for its permits.

Table 1. Permits, pollution, welfare and local taxes under different regimes

	1. First-best	2. Permits market (optimal pollution as initial allocation)	3. Optimal permits $\varphi_i \lesseqgtr 0$; $\varphi_i \lesseqgtr 0$ & $u_i \geq 0$ [a)]	4. Optimal permits: $\varphi_i \geq 0$; $\varphi_i \geq 0$ & $u_i \geq 0$ [a)]	5. permits market	6..Equal allocation of permits: $\varphi_i \lesseqgtr 0$	7. Equal allocation of permits: $\varphi_i \lesseqgtr 0$ & $u_i \geq 0$
$\sum x_i$	1.1185	1.1185	1.1185	1.1185	1.1185	1.1185	1.1185
x_1	-	0.1944	0.1846	0.3628	0.1889	0.3728	0.3728
x_2	-	0.5856	0.5777	0.5229	0.5734	0.3728	0.3728
x_3	-	0.3386	0.3562	0.2329	0.3562	0.3728	0.3728
e_1	0.1944	0.1818	0.1944	0.1944	0.1818	0.2259	0.2088
e_2	0.5856	0.6040	0.5856	0.5856	0.6040	0.5052	0.4572
e_3	0.3386	0.3328	0.3386	0.3386	0.3328	0.3875	0.3541
W_1	-0.0010	0.1043	-0.0068	0.0530	-0.0091	0.0305	0.1029
W_2	0.6673	0.5391	0.6627	0.6472	0.6626	0.5926	0.5091
W_3	0.4303	0.4510	0.4408	0.3963	0.4407	0.4456	0.4524
$\sum W_i$	1.0966	1.0943	1.0966	1.0966	1.0943	1.0687	1.0645
φ_1			-0.2741	0		-0.5526	-0.3791 (0.0985) [b)]
φ_2			0.0450	0.3191		0.6667	0.4264
φ_3			-0.0470	0.2272		0.0252	-0.0484
τ		0.6159	0.5952	0.3211	0.6159	0.1063	0.6579

[a)] State bans are allowed, but the federal government permits allocation keeps the states from implementing them. [b)] State 1 issues a state ban of 0.0985 in this case.

Column 4 provides details on the optimal distribution of permits in case the state authorities are bound not to subsidise emissions, due to e.g., pressure from NGO's, as mentioned in Santore *et al*. First of all, it turns out that the first-best optimum can be realised in this setting. A remarkable feature is that state 1 benefits considerably, and state 3 loses, compared to the first-best optimum. For the distribution of total welfare across the states, it appears to be important whether positive or negative local taxes are allowed**.** The point is simply that in order to prevent state 1 to subsidise pollution a large allocation of permits to this state is needed. This obviously goes at the cost of fewer permits for the other states who have lower welfare levels as a result. It is noteworthy, that if in this case and the previous one, trade bans by the states were allowed, no single state would have an incentive to introduce one. Obviously, as the federal government determines permits such that both first-best production levels are obtained and the locally optimal taxes by each state are set, no state has an incentive to change the number of permits by a trade ban as that would imply a utility loss.

Column 5 depicts a particular case of laissez-faire. Total permits issued are set equal to the total number of permits that corresponds with the first-best optimum. The distribution of the permits across the states has been chosen such that a Pareto improvement occurs if this TEP-system is replaced by a system with (possibly negative) state taxes, combined with an optimal distribution of permits (column 3). This provides an example for the claim that an unrestrained TEP market can be beaten by a system where states intervene in the market and the federal government allocates permits optimally. As expected, the unrestrained permits markets leads to a uniform decline in individual welfare, compared to a more sophisticated approach.

By way of contrast with the optimal distribution of permits, in column 6 the effects are given for the case where the federal government allocates the total optimal amount of permits (1.1185) in equal proportions across the states, whereas no trade bans are allowed. As the allocation of permits across states is arbitrary, this case, therefore, fits the analysis of Santore *et al.* (2001). In line with Santore *et al.* total welfare is lower than first-best total welfare (1.0687 instead of 1.0966), but as state 1 gets more permits in this scenario than in the "first-best" scenarios, state 1 will gain. Notice that unlike Santore *et al.* we allow for subsidies on internal pollution. The high number of received permits provides state 1 with an additional incentive to impose negative taxes on firms within the own border. Indeed, the subsidies are twice as high as in the first-best case of column 3. However, as a counterforce to that state 2 is strongly increasing its local tax which drives down the permits price, but especially decreases production, and thus pollution, by state 2. This is also beneficial for state 1.

Welfare for state 1 (and 3) will be boosted even more, if trade bans are allowed, as can be seen from column 7. State 2 now has an even lower pollution, and imposes a lower tax than in the case of column 6. For state 2 the local tax is less effective as an instrument to contain the increase of the permits price. This price is heavily affected by the imposed trade ban of 0.0985 by state 1. This reflects again that in the numerical constellation from the point of view of the federal government it is not efficient to put much emphasis on redressing emissions in state 1. For state 1, of course, the reverse holds. State 1 is a 'hot spot', i.e., most of the nation-wide pollution is emitted in that state. By decreasing the effect of pollution in state 1, welfare in state 1 increases considerably. This goes at the cost of lower production in the other states. As these states have relatively low marginal production costs, the electricity consumers nation-wide are harmed by this measure. Apparently, this latter welfare loss is not compensated by the welfare gain due to lower pollution experienced by the state 1 consumers.

The result of column 7 also illustrates that local environmental policy, possibly leading to trade bans, can be a very effective instrument from the point of view of the state applying these instruments. According to our proposition 2, from a welfare point of view the instrument of trade bans cannot be reconciled with a centrally set environmental policy. However, we supposed that the federal government had utilitarian types of social-welfare functions. Column 7 suggests that a federal government might support the deployment of trade-ban policies by local governments if the federal social-welfare function is of a Rawlsian type instead of a utilitarian type. In that case, the low welfare in state 1 will get a relatively large weight in the preference of the federal government, and the federal government might consent the use of trade bans[3]

6. Conclusions

In the present paper we have investigated tradable permit systems in a federal state, where pollution is transboundary across states and individual states can conduct environmental policy by means of emissions taxation and trade bans with regard to permits. The main outcome is that in the design of the initial allocation to individual states the central authority should take the discretionary power of the states into account. In doing so it can set the initial allocation such that overall social welfare corresponds to first-best. Moreover, the government can through an appropriate allocation of initial permits prevent the occurrence of trade bans on emissions permits. However, if the initial allocation is not efficient in the first-best sense individual states may benefit from imposing unilateral trade restrictions. In spite of these results some caution is appropriate as to the actual implementation of the proposed policy, in view of the informational burden on the federal government in calculating the optimal distribution. More research is needed into the question how much information (on costs, transportation coefficients, and local welfare weights) the federal government needs for her allocation policy in order to approach the first-best solution to a satisfactory degree.

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[3] Incidentally, when New York state announced a fine on the sale of permits by New York state firms, the federal government did not object.

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