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EFFICIENCY OF NON-COOPERATIVE EMISSION TAXES IN PERFECTLY COMPETITIVE MARKETS*

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With the current efforts to regulate the emissions of greenhouse gases and other cross border pollutants, the question of environmental federalism is as important as ever. By generalising the model presented by Oates and Schwab (1987, 1988), we show that the well established result within environmental federalism, that the government of a small country has no incentive to depart from the cooperative choice of environmental standards, does not hold for pollutants that have regional or global characteristics, as e.g. sulphur dioxide and carbon dioxide has. (JEL: H77, Q58)

1. Introduction

With the current efforts to cut the emission of greenhouse gases, the question of environmental federalism – the division of responsibility for environmental regulation between different levels of government – deserves as much attention as ever. Current implementations vary. In the EU, for example, the price of emitting CO_2 has been harmonised for major stationary emitters. However, in other areas of environmental management, there are still large differences within the EU. One of these fields is the level of support to renewable electricity sources. Within this field, cooperation attempts at the EU level have been short-lived due to fierce opposition they have been met by some member states.

Within environmental federalism, an important question is the efficiency of non-cooperative environmental standards. A well established result within the literature is that, in perfectly competitive markets, a small state has no incentive to depart from the cooperative choice of environmental standards as long as pollution generated in one jurisdiction doesn't spill over into another. Two of the first ones to show this formally were Oates and Schwab (1987, 1988). Our objective is to extend their analysis by allowing for regional, e.g. SO_2, and global pollutants, e.g. CO_2. Most previous work, both within the strand that assumes perfect and within the strand that assumes imperfect competition, only consider local pollutants. Cross-border pollutants are, in our opinion, underrepresented. Thus, our aim is to contribute to the strand of literature that deals with them. We acknowledge that our assumption of perfect competition, inherited from Oates and Schwab, is a crude simplification, but we hope that our analysis will serve as a starting point for more elaborate analyses.

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The paper is structured as follows. In Section 2, we review the main contributions within the field of environmental federalism. In Section 3, we outline the model and derive equilibrium conditions for the amount of capital employed and emissions generated by each state. In Section 4, we study some of the comparative statics of a unilateral emission tax increase. In Section 5 and 6, we derive the non-cooperative and co-operative choice of emission taxes, respectively. Section 7 concludes.

2. A brief literature review

Since the early papers of the 1970s and 1980s, among others Cumberland (1979, 1981) and Oates and Schwab (1987, 1988), the body of literature within environmental federalism has expanded along a number of different themes. Most importantly, with new insights on how to model imperfect competition, the literature has expanded to include markets where either producers or jurisdictions, or both, can affect prices.

A well established result within the strand that assumes perfect competition between the polluting firms is that a small country has no incentive to depart from the cooperative choice of environmental standards, assuming there are no pollution spillovers between states, see e.g. Rauscher (1994) or Ulph (1997). If trade policy is not banned, this result holds regardless of whether the countries are large or small, i.e. whether they can influence world prices or not. However, if trade policy is banned, the government of a large country may use environmental policy to improve its terms of trade. The government of a small country, however, has no incentive to depart from the cooperative equilibrium, because by assumption it cannot influence the country's terms of trade, and failure to internalise environmental externalities is welfare reducing.

The results within the strand of literature that assumes less than perfect competition between the polluting firms are less conclusive. Early work within this strand relies on oligopoly models in the tradition of Brander and Krugman (1983) and Brander and Spencer (1985), and assumes that firms are immobile. Relying on the Cournot duopoly presented by Brander and Spencer (1985), Barrett (1994) shows that in the absence of trade policy, governments will bid down each others' environmental standards to shift profits toward domestic producers. However, if firms compete in prices rather than quantities, they will bid up each others' standards. More recent work, originating from Markusen et al. (1995), assumes that firms are mobile. As with immobile firms, the finding of Markusen et al. is that without cooperation, governments will either bid up or down each others' emission taxes. However, the determining factor is not whether firms play Cournot or Stackelberg, but the disutility of pollution. If the disutility of pollution is large enough, the states will increase their emission taxes until the polluting firms are driven out of business.

Subsequent research has made additional simplifications, especially regarding transportation costs while relaxing others, such as the number of countries (Rauscher 1995) and the number of firms (Greaker 2003, Hoel 1997, Ulph and Valentini 2001). With exception of Rauscher, the results are in line with Markusen et al. Of the above mention analyses, Rauscher is the only who allows for pollution spillovers. He reports that the opportunity cost, in terms of environmental damages, of undercutting foreign environmental regulations becomes infinitesimally small if pollution is perfectly global.

Within the non-competitive strand, Pflüger (2001) pursues an alternative strategy, but as most of the previous research, assumes that pollution is strictly local. Relying on the model of monopolistic competition by Dixit and Stiglitz (1977), Pflüger shows that choice of emissions tax by one state imposes a number externalities on the other, both positive and negative. Non-cooperative taxes are lower than cooperative taxes if the importance of emissions in production, relative to labour, is small in comparison to transport costs and the mark-up on average variable costs. However, in contrast with the oligopoly model by Markusen et al. (1995), in Pflüger the disutility of pollution is not among the parameters that separate the non-cooperative choice from the cooperative choice.

3. Model outline

Following Oates and Schwab (1987, 1988), we analyse the choice of emission taxes, τ^i, in an assymmetric general equilibrium model of a federal economy of small states. The states are small in the sense that they cannot influence the rate of return to capital, *R*, and thus treat it as exogenous. In the spirit of the original model, we assume that capital and goods are perfectly mobile. Labour, in contrast, is perfectly immobile. Thus, the supply of labour is fixed in each state.

Emissions, E^i, are generated as a by-product in the manufacturing of a homogeneous private good. Besides emissions, production requires capital, K^i, and labour, L^i. Following Oates and Schwab, we assume that the good is manufactured by perfectly competitive firms with technologies that may vary across states, but all of which exhibit constant returns to scale with regard to the three inputs.

The property of constant returns to scale and the assumption of a fixed supply of labour allow us to write the production functions in per worker terms, $F^i\left(K^i, L^i, E^i\right) = L^i f^i\left(k^i, e^i\right)$. By partial derivation of it with respect to K^i, L^i and E^i, we obtain the marginal products of capital, labour, and emissions as

$$F^i_{K^i}\left(\cdot\right) = f^i_{k^i}\left(\cdot\right),$$

$$F^i_{L^i}\left(\cdot\right) = f^i\left(\cdot\right) - k^i f^i_{k^i}\left(\cdot\right) - e^i f^i_{e^i}\left(\cdot\right), \text{ and}$$

$$F^i_{E^i}\left(\cdot\right) = f^i_{e^i}\left(\cdot\right),$$

respectively, where subscripts denote partial derivatives. We assume that the marginal products of $f^i\left(k^i, e^i\right)$ are positive but diminishing, and that $f^i_{k^i e^i}\left(\cdot\right) > 0$ and $f^i_{e^i k^i}\left(\cdot\right) > 0$, i.e. that capital and emissions are q-compliments, using the definition by Seidman (1989).

As price takers, firms will employ capital up to the point where the marginal unit earns just enough to cover its cost. Thus, in equilibrium,

$$(1) \qquad f^i_{k^i}\left(\cdot\right) = R, \text{ for all states } i,$$

by choosing the private good as the numéraire. As with capital, firms choose a level of emissions which equates the marginal product of emission with the tax rate. Thus, in equilibrium,

$$(2) \qquad f^i_{e^i}\left(\cdot\right) = \tau^i, \text{ for all states } i.$$

We assume that within each state, workers are identical in both preferences and productive capacity, and that they are paid a wage equal to their marginal product. In addition to wages, workers receive tax income, $e^i\tau^i$, and exogenous income, b^i. For simplicity, we assume that all capital is owned by foreigners. With this simplification, we can write the budget constraint of the representative worker, resident of state *i* as

$$(3) \quad x^i = f^i\left(\cdot\right) - k^i f^i_{k^i}\left(\cdot\right) - e^i f^i_{e^i}\left(\cdot\right) + e^i\tau^i + b^i,$$

where x^i is the consumption of the private good. Consumption of it increases utility $u^i = u^i\left(x^i, O^i\right)$, whereas exposure to pollution, O^i, reduces utility. We define the level of pollution as $O^i = O^i\left(e^1, \ldots e^i, \ldots, e^n\right)$, where the sign of the partial derivatives depend on the type of pollutant. We examine four distinct types of pollutants, shown in Table 1.

We distinguish here between two types of regional pollutants, those that affect the level of pollution both in the source state and in neighbouring states, and those that affect neighbour-

Table 1. Types of pollutants

Type of pollutant	**Pollution function characteristics**
Local	$O^i_{e^i}\left(\cdot\right) > 0$, $O^i_{e^j}\left(\cdot\right) = 0 \;\forall j \neq i$
Regional and partially transboundary	$O^i_{e^j}\left(\cdot\right) > 0 \;\forall i, j$
Regional and perfectly transboundary	$O^i_{e^i} = 0$, $O^i_{e^j}\left(\cdot\right) > 0 \;\exists j \neq i$
Global pollutant	$O^i_{e^i}\left(\cdot\right) = O^i_{e^j}\left(\cdot\right) > 0 \;\forall i, j$

ing states only. An example of the former is wastewater emissions is context of the Baltic Sea. An example of the latter is emissions of SO_2 that only affect neighbouring states.

4. Comparative statics of an unilateral emission tax change

Total differentiation of the equilibrium conditions (1) and (2) with respect to k^i, e^i and τ^i, yields the following system of equations

$$\begin{bmatrix} f^i_{k^ik^i}(\cdot) & f^i_{k^ie^i}(\cdot) \\ f^i_{e^ik^i}(\cdot) & f^i_{e^ie^i}(\cdot) \end{bmatrix}\begin{bmatrix} dk^i \\ de^i \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix} d\tau^i.$$

From Cramer's rule, it follows that

$$\frac{dk^i}{d\tau^i} = \frac{-f^i_{k^ie^i}(\cdot)}{A} < 0 \text{ and that } \frac{de^i}{d\tau^i} = \frac{f^i_{k^ik^i}(\cdot)}{A} < 0,$$

because $A = f^i_{k^ik^i}(\cdot)f^i_{e^ie^i}(\cdot) - f^i_{k^ie^i}(\cdot)f^i_{e^ik^i}(\cdot) > 0$, as we show in Appendix 1. Thus, increasing the tax rate reduces both the amount of capital employed and the amount emissions generated by a particular state.

5. Non-cooperative choice of emission taxes

Without coordination, national governments maximise the utility of the representative domestic consumer, u^i, subject to budget constraint in (3) and to the factor demands in (1) and (2). The Lagrangian for the non-cooperative maximisation problem can be written as

$$\begin{aligned} \Gamma \equiv\ & u^i(x^i, O^i) \\ & -\lambda\left[x^i - b^i - e^i\tau^i - f^i(\cdot) + k^i f^i_{k^i}(\cdot) + e^i f^i_{e^i}(\cdot)\right] \\ & -\gamma\left[f^i_{k^i}(\cdot) - R\right] \\ & -\eta\left[f^i_{e^i}(\cdot) - \tau^i\right] \end{aligned},$$

and the FOCs, with respect to x^i, e^i, k^i and τ^i, respectively, as

$$\lambda = u^i_{x^i}(\cdot),$$

(4) $$u^i_{O^i}(\cdot)O^i_{e^i}(\cdot) + \lambda\tau^i - \lambda k^i f^i_{k^ie^i}(\cdot) - \lambda e^i f^i_{e^ie^i}(\cdot) - \gamma f^i_{k^ie^i}(\cdot) - \eta f^i_{e^ie^i}(\cdot) = 0,$$

(5) $$-\lambda k^i f^i_{k^ik^i}(\cdot) - \lambda e^i f^i_{e^ik^i}(\cdot) - \gamma f^i_{k^ik^i}(\cdot) - \eta f^i_{e^ik^i}(\cdot) = 0, \text{ and}$$

(6) $$\eta = -\lambda e^i.$$

By substituting (6) into (5), we obtain $\gamma = -\lambda k^i$. By substituting this and the expressions for the two other Lagrange multipliers into (4) yield

(7) $$\tau^i = -\frac{u^i_{O^i}(\cdot)O^i_{e^i}(\cdot)}{u^i_{x^i}(\cdot)}.$$

Equation (7) says that, without cooperation, national governments set a tax equal to marginal social damage to domestic workers. The damage is measured in terms of the willingness to sacrifice consumption in return for a decrease in the level of pollution.

6. Cooperative choice of emission taxes

Through cooperation, the welfare of neighbouring states is taken into consideration when deciding on the level of emission tax. Thus, the constraints are the same as in the non-cooperative case with one addition, the constraint of not reducing welfare abroad below a certain level. Here, this level is given by $\hat{u}^s$. The additional constraint captures the effect of decisions in one state on the welfare in other states. With these changes, the Lagrangian for the cooperative maximisation problem can be written as

$$\begin{aligned} \Lambda \equiv\ & u^i(x^i, O^i) \\ & -\lambda\left[x^i - b^i - e^i\tau^i - f^i(\cdot) + k^i f^i_{k^i}(\cdot) + e^i f^i_{e^i}(\cdot)\right] \\ & -\gamma\left[f^i_{k^i}(\cdot) - R\right] \\ & -\eta\left[f^i_{e^i}(\cdot) - \tau^i\right] \\ & -\sum_{\substack{s=1 \\ s\neq i}}^{n} \xi^s\left[\hat{u}^s - u^s(x^s, O^s)\right] \end{aligned}.$$

Since $\xi^s = -\partial\Lambda / \partial\hat{u}^s$, we can interpret ξ^s as the shadow prices, measured in units of u^i, that domestic consumers must to pay to increase utility abroad. $\partial\Lambda / \partial\hat{u}^s \leq 0$ because the only way for domestic consumers to improve welfare abroad is by reducing emissions. Assuming that the domestic level of emissions is optimal, reducing them further cannot be welfare improving. It follows that $\xi^s \geq 0$.

The FOCs, with respect to x^i, e^i, k^i and τ^i, respectively, can be written as

$$\lambda = u^i_{x^i}(\cdot),$$

$$u^i_{O^i}(\cdot)O^i_{e^i}(\cdot) + \lambda\tau^i - \lambda k^i f^i_{k^i e^i}(\cdot) - \lambda e^i f^i_{e^i e^i}(\cdot)$$

$$-\gamma f^i_{k^i e^i}(\cdot) - \eta f^i_{e^i e^i}(\cdot) + \sum_{\substack{s=1 \\ s\neq i}}^{n} \xi^s u^s_{O^s}\left(x^s, O^s\right) \cdot O^s_{e^i}(\cdot) = 0$$

$$-\lambda k^i f^i_{kk^i}(\cdot) - \lambda e^i f^i_{ek^i}(\cdot) - \gamma f^i_{kk^i}(\cdot) - \eta f^i_{ek^i}(\cdot) = 0,$$

and $\eta = -\lambda e^i$.

By performing the same substitutions as in the non-cooperative case, we obtain

$$(8) \quad \tau^i = -u^i_{O^i}(\cdot)O^i_{e^i}(\cdot) / u^i_{x^i}(\cdot) - \sum_{\substack{s=1 \\ s\neq i}}^{n} \xi^s u^s_{O^s}\left(x^s, O^s\right) \cdot O^s_{e^i}(\cdot) / u^i_{x^i}(\cdot).$$

The difference between the cooperative and non-cooperative tax level, (8) and (7), respectively, is

$$-\sum_{\substack{s=1 \\ s\neq i}}^{n} \xi^s u^s_{O^s}\left(x^s, O^s\right) \cdot O^s_{e^i}(\cdot) / u^i_{x^i}(\cdot),$$

which represents the negative trans-state externality in our model, i.e. the effect of domestic emission on the level of pollution, and welfare, abroad. For regional and global pollutants, the term is larger than zero, because there is a state abroad for which $O^s_{e^i}(\cdot) > 0$. It follows, that for regional and global pollutants, the non-cooperative level of emission taxes is inefficiently low. For local pollutants, the term is zero, because $O^s_{e^i}(\cdot) = 0$ for all states s abroad. It follows, that for local pollutants, the non-cooperative level of emission taxes is efficient.

Regional pollutants that are perfectly transboundary, e.g. emission of SO_2 that only affect neighbouring states, illustrates nicely the lack of incentives. The domestic government has no incentive to regulate them since the damage is borne entirely by neighbouring states. Thus, the domestic government chooses a zero tax rate. Obviously, this is inefficient.

7. Discussion and policy implications

The inefficiency arises because national governments, by assumption, care only for costs and benefits that accrue to domestic consumers; the utility from more consumption accrue in full to domestic workers, whereas the disutility from more pollution is borne only partially by domestic consumers. The only way to internalise the pollution externality, and remove the inefficiency, is by cooperation. Thus, our recommendation is that that the regulation of regional and global pollutants, or the activities that cause them, such as the use of fossil fuels in electricity generation and the associated generation of CO_2 and SO_2, should be coordinated at the federal level.

Appendix 1

The per-worker profit of a firm producing in state i is given by $f^i\left(k^i,e^i\right)-Rk^i-\tau^i e^i$. The FOCs of the firm's problem are $f^i_{k^i}\left(\cdot\right)-R=0$ and $f^i_{e^i}\left(\cdot\right)-\tau^i=0$. The SOCs is that the Hessian,

$$H=\begin{bmatrix} f^i_{k^ik^i}\left(\cdot\right) & f^i_{k^ie^i}\left(\cdot\right) \\ f^i_{e^ik^i}\left(\cdot\right) & f^i_{e^ie^i}\left(\cdot\right) \end{bmatrix},$$

is negative definite. For negative definiteness, the leading principal minors must alternate in sign, with the first leading principal minor being negative, i.e. $f^i_{k^ik^i}\left(\cdot\right)<0$ and $f^i_{k^ik^i}\left(\cdot\right)f^i_{e^ie^i}\left(\cdot\right)-f^i_{k^ie^i}\left(\cdot\right)f^i_{e^ik^i}\left(\cdot\right)>0$.

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