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Interjurisdictional Competition in Emission Taxes under Imperfect Competition of Local Firms

by

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Abstract

This paper provides a model of interjurisdictional tax competition. Local governments levy emissions taxes on residing firms and provide a public good that benefits consumers. We show that the equilibrium tax rates do not coincide with their second-best levels and illuminate the reasons why local governments deviate from cooperative solution. Although, in the general case of heterogeneous regions and interregional pollutant transmission, some governments may determine their equilibrium emission taxes too high, we show that the opposite is 'more likely'. Namely, governments of identical regions deviate from cooperative solution by lowering their tax rates. This result gives some support to the hypothesis that interjurisdictional tax competition leads to 'ecological dumping'.

Keywords: interjurisdictional tax competition, emission taxation, local public goods, asymmetric Cournot competition, pollutant transmission.

(JEL: H32, H41, H73, R34, R50)

1 Introduction

In recent years the analysis of regulating oligopolies through emission taxes was pushed forward. Attention was focused on equilibrium emissions, output quantities, and the number of firms.[1] One common characteristic of these models is that *one* regulator determines a uniform tax rate for *all* competing firms. But often firms do not reside in *one* jurisdiction and thus are not liable to the same tax regime. Especially, if state governments (or even the authorities of the counties) fix emission taxes, different firms are confronted with different prices of environmental inputs. On the other hand, the international trade literature – as far as it deals with emission taxation – considers this fact but implies other drawbacks. Either the firms (exclusively) compete on third country's market[2] and/or tax revenues are redistributed to residents by lump-sum transfers. In the first case, local residents do not consume this item; in the second case, private marginal utility of income equals marginal value of public funds.[3] In addition, many authors restrict their analysis by assuming identical firms and/or countries (e.g., KENNEDY (1994)). We avoid these limitations and present a more general model of interjurisdictional tax competition. We allow for different firms producing a consumer good by the use of environmental inputs (emissions). Each firm exhibits Cournot behavior and is regulated by a local government through the imposition of a local emission tax. Tax revenues are spent on the provision of a local public good which benefits local residents. Local governments determining their emission tax rates engage in interjurisdictional tax competition. Because neither the firms nor the residents are assumed to be identical, local welfare functions differ regionally and asymmetric equilibria may emerge. We show that the equilibrium tax rates do not coincide with their cooperative, i.e., second-best, levels and that three main effects are responsible for this: external environmental damages, fiscal externalities, and interregional production shifting. Although, literature suggests that for identical regions equilibrium tax rates coincide with their optimal levels, if pollution is purely local and firms behave perfectly competitive, this need not to be true. If local public goods are inefficiently provided, equilibrium tax rates

[1] See for example EBERT (1992) and REQUATE (1994).

[2] See for example ULPH (1992) and CONRAD (1993).

[3] This commonly made assumption of partial analysis implies that local governments have unlimited access to head taxation and thereby are enabled to provide local public goods at efficient levels.

differ from marginal damage. Even if no other effects are present, it is the fiscal effect that distorts equilibrium emission tax rates from their cooperative levels.

This paper is organized as follows. Section 2 sets up the model by depicting the behavior of the private sector, firms and consumers. In section 3 we derive the equilibrium tax rates as well as their cooperative, i.e., second-best, levels. A comparison of both tax rates reveals the sources of inefficiency.[4] Section 4 summarizes the paper.

2 The Model

2.1 The Local Firms

Consider a nation (or union) that consists of n regions (or states) where in each jurisdiction there is one resident firm. These n local firms producing one homogeneous output good compete on a national market.[5] Each firm $j = 1, \ldots, n$ produces its output, Q^j, by, among others, the use of environmental inputs (emissions), E^j. Since the employment of all other factors is already optimized for each output level, the associated production costs solely depend on output and emissions, $C^j(Q^j, E^j)$. The cost function, C^j, is supposed to be strictly convex with[6] $C^j_q > 0$ and $C^j_{qe} < 0$. If in region j the local government imposes a constant tax rate, τ^j, on emissions (linear tax scheme), the local firm incurs additional cost of $\tau^j E^j$.

Each firm's revenue is determined by its supply level and by the market price which depends on total supply, $Q := \sum_{j=1}^{n} Q^j$. We assume that firms engage in Cournot competition facing a downward sloping inverse demand curve, P, which

[4]By 'sources of inefficiency' we mean those incentives that prompt local governments to deviate from cooperative behavior.

[5]Since the number of firms equals to the number of jurisdictions, we implicitly assume that the total number of competing firms is exogenously fixed and not too large ($n << \infty$). The entry of new firms may be prevented by prohibitively high fixed cost which are already endured by the established firms. REQUATE (1994) considers an endogenous number of firms where all firms reside in one jurisdictions.

[6]Subindices of functions denote partial derivatives as long as not stated otherwise.

is 'not too convex' in the sense that[7]

$$P''(Q) \leq -\frac{P'(Q)}{Q} \quad \forall Q \in \mathbb{R}_{+}. \tag{1}$$

Among others, condition (1) ensures that revenue $R(Q^j, \cdot) = P(Q)Q^j$ is a concave function in Q^j which, together with the convexity of C^j, implies that profit is concave in Q^j and E^j. Writing $Q^{-j} := \sum_{i \neq j} Q^i$, we can define the profit of firm j, which is located in jurisdiction j, as

$$\Pi^j(Q^j, E^j; Q^{-j}, \tau^j) = P(Q)Q^j - C^j(Q^j, E^j) - \tau^j E^j. \tag{2}$$

For each firm $j = 1, \ldots, n$ its profit maximizing policy, with respect to (w.r.t.) Q^j and E^j, is determined by the first order conditions (f.o.c.s)[8]

$$P(Q) + P'(Q)Q^j - C^j_q(Q^j, E^j) = 0, \tag{3}$$

$$-\tau^j - C^j_e(Q^j, E^j) = 0. \tag{4}$$

For a given vector of local emission tax rates, $\vec{\tau} := (\tau^1, \ldots, \tau^n)'$, the system of the $2n$ f.o.c.s, given by (3) - (4), determines firms' equilibrium output and emission levels, $\{Q^j(\vec{\tau}), E^j(\vec{\tau})\}_{j=1,\ldots,n}$.

2.2 The Consumers

Let local consumers' preferences for the private good be represented by a local demand function $d^j(p^j) \forall j = 1, \ldots, n$. Accordingly, let $p^j(q^j)$ denote the local inverse demand function. Since there is one national market for the private good, the (equilibrium) price must be the same everywhere. Using $p^j = p^i \forall i, j$ and aggregating local demands, $D(p) := \sum_{j=1}^n d^j(p)$, we can derive the national inverse demand function $P(Q)$. From market clearing we know that demand equals supply,

$$D(p) = \sum_{j=1}^n q^j = \sum_{j=1}^n Q^j = Q,$$

[7] This condition is slightly stronger than that one which is sufficient to ensure the concavity of the profit, $P''(Q) \leq -\frac{2P'(Q)}{Q}$.

[8] To keep mathematical expressions readable we omit any tags for indicating 'optimal' values of variables throughout this paper. Therefore, it is pointed out to the reader that the same symbol may mean diverse, if the variable is evaluated at different points.

where $q^j = d^j(p)$. Hence, local residents' consumer surplus is given by

$$\int_0^{q^j} p^j(\xi)d\xi - P(Q)q^j.$$

In each region j local residents hold all shares of the local firm and therefore gain its full profits. Furthermore, local residents benefit from the provision level of a local public good, G^j, which is financed by revenues from local emission taxation, $\tau^j E^j$. We model the provision of local public goods as purchases and public provision of private goods. This means, that we measure the supply of public goods by its related costs. For ease of tractability, we rule out interregional spillovers of local public goods. Thus, non-residents are perfectly prevented from using local public goods (of other regions) at zero costs; i.e., we deal with pure local public goods.

On the other hand, residents suffer from industrial pollutant emission directly and indirectly: First, pollutant emissions worsen the prevailing environmental quality; and second, they deteriorate the consumption conditions of public services by diminishing the use of a given provision level.[9] Let $E := \sum_{j=1}^{n} E^j$ denote total national pollutant emissions. The (composed) utility derived by residents of region j from the provision of the local public good and from aggregate emissions is denoted by $U^j(G^j, E)$.[10] We assume that U^j is monotonically increasing in G^j, monotonically decreasing in E, and concave in its arguments.[11] In total, the welfare of the residents of region j is equal to

$$\mathcal{W}^j = \int_0^{q^j} p^j(\xi)d\xi - P(Q)q^j + U^j(G^j, E) + \Pi^j(Q^j, E^j; Q^{-j}, \tau^j), \qquad (5)$$

where firm's profits are given by (2) and the public budget constraint equates revenues and spendings, $G^j = \tau^j E^j$.

[9]For example, visitor's utility derived from the consumption of a recreation area may depend on the levels of air and noise pollution.

[10]Note that this specification implies that pollutant transmission is perfectly transboundary. Because we concentrate rather on interjurisdictional than on international tax competition, it seems to be sensible to assume that pollutant emission in one region affects the environmental quality of other regions (more or less) immediately. However, the case where pollutants are only partially transmitted can easily be included in our model.

[11]Alternatively, the function U^j can be interpreted as the social evaluation of public funds dependent on environmental quality. If U^j is additively separable, i.e., emissions do not affect the social value of public funds (and reverse), $U^j(G^j, E) = \tilde{U}^j(G^j) - D^j(E)$, and if, in addition, $\tilde{U}^j$ is linear in public revenues, U^j simplifies to the evaluation of public revenues by the social price of public funds, λ, net of environmental damage: $U^j(G^j) = \lambda G^j - D^j(E) = \lambda \tau^j E^j - D^j(E)$.

3 Welfare Analysis: Nash Tax Rates versus Cooperative Tax Rates

In this section we derive the Nash solution of interjurisdictional tax competition, i.e., the optimal policy of each local government given the (optimal) tax rates of all other regions. Afterwards, we examine how local governments set their tax rates if they behave cooperatively and compare these tax rates with their equilibrium levels. This enables us to discover the incentives that prompt local governments to deviate from cooperative solution. But before turning to this, we have to investigate further the equilibrium supply and emission level of a single firm and the corresponding aggregate values.

3.1 Comparative Statics of Supply and Emission Demand

Suppose that the local government of region j considers a change of its emission tax rate, τ^j. In order to evaluate this policy measure one needs to know the effect of τ^j on the equilibrium values of Q^j, E^j, Q^{-j}, E^{-j} ($E^{-j} := \sum_{i \neq j} E^i$), and thereby on its aggregates Q and E.

Differentiating (4) w.r.t. τ^j yields

$$\frac{\partial E^i}{\partial \tau^j} = \begin{cases} -\dfrac{1 + C^j_{qe} Q^j_{\tau^j}}{C^j_{ee}} & \text{for } i = j, \\ -\dfrac{C^i_{qe} Q^i_{\tau^j}}{C^i_{ee}} & \text{for } i \neq j. \end{cases} \tag{6}$$

Analogous differentiating of (3) using (6) yields

$$Q^j_{\tau^j}\left(P' - \frac{1}{C^j_{ee}}\left(C^j_{qq}C^j_{ee} - C^{j^2}_{qe}\right)\right) + Q_{\tau^j}\left(P' + P''Q^j\right) = -\frac{C^j_{qe}}{C^j_{ee}}, \tag{7}$$

$$Q^i_{\tau^j}\left(P' - \frac{1}{C^i_{ee}}\left(C^i_{qq}C^i_{ee} - C^{i^2}_{qe}\right)\right) + Q_{\tau^j}\left(P' + P''Q^i\right) = 0 \quad \forall i \neq j. \tag{8}$$

Note that the term $C^i_{qq}C^i_{ee} - C^{i^2}_{qe}$ is the determinant of the Hessian of C^i which is by strict convexity positive ($det(Hess(C^i)) > 0$).

Let $a^i := P' + P''Q^i < 0$ and $b^i := P' - [det(Hess(C^i))/C^i_{ee}] < 0 \; \forall i = 1, \ldots, n$. Solving (8) for $Q^i_{\tau^j}$, summing up over all $i \neq j$, and using

$$Q_{\tau^j} \equiv Q^j_{\tau^j} + Q^{-j}_{\tau^j} \tag{9}$$

yields

$$Q^{-j}_{\tau^j} = -Q_{\tau^j} \sum_{i \neq j} \frac{a^i}{b^i}.$$

Substituting this into (9) and solving for $Q^j_{\tau^j}$ gives

$$Q^j_{\tau^j} = \left(1 + \sum_{i \neq j} \frac{a^i}{b^i}\right) Q_{\tau^j}.$$

Substituting into (7) and rearranging terms yields

$$Q^j_{\tau^j} = -\frac{C^j_{qe}}{C^j_{ee}} \frac{1 + \sum_{i \neq j} \frac{a^i}{b^i}}{a^j + b^j \left(1 + \sum_{i \neq j} \frac{a^i}{b^i}\right)} < 0, \tag{10}$$

$$Q^{-j}_{\tau^j} = \frac{C^j_{qe}}{C^j_{ee}} \frac{\sum_{i \neq j} \frac{a^i}{b^i}}{a^j + b^j \left(1 + \sum_{i \neq j} \frac{a^i}{b^i}\right)} > 0, \tag{11}$$

$$Q_{\tau^j} = -\frac{C^j_{qe}}{C^j_{ee}} \frac{1}{a^j + b^j \left(1 + \sum_{i \neq j} \frac{a^i}{b^i}\right)} < 0. \tag{12}$$

If the local government of region j increases its emission tax, the local firm responds to this by a decrease of its output, whereas non-resident firms enhance their output quantities. Aggregating these variations we see that, although Q^{-j} increases, total supply decreases, if the government of one single jurisdiction raises its emission tax rate.

Substituting (10) - (12) into (6) gives us the signs of the variations of emissions:

$$E^j_{\tau^j} < 0, \qquad E^i_{\tau^j} > 0 \; \forall i \neq j, \qquad E^{-j}_{\tau^j} > 0. \tag{13}$$

Analogously to (10) and (11), the use of environmental inputs decreases in jurisdiction j and increases in all other jurisdictions as τ^j increases. But contrary to Q_{τ^j}, and although we can unambiguously determine the sign of the derivative of each local emission, we are not able to decide, in general, whether total pollutant emissions rise or fall. To see this, sum up $E^i_{\tau^j}$ over all i. Using (10) - (12) we can write the derivative of total emissions as

$$E_{\tau^j} = -\left[\frac{1}{C^j_{ee}} + Q_{\tau^j}\left(\frac{C^j_{qe}}{C^j_{ee}} + \sum_{i \neq j}\left(\frac{C^j_{qe}}{C^j_{ee}} - \frac{C^i_{qe}}{C^i_{ee}}\right)\frac{a^i}{b^i}\right)\right]. \tag{14}$$

Since we do not know whether the sum in (14) is positive or negative, the sign of E_{τ^j} is indeterminate. For the special case of identical firms and equal tax rates in all jurisdictions, the sum term drops out and total emissions fall if one single government raises its tax rate. In particular, we get

$$
\begin{aligned}
E^j_{\tau^j} &= -\left(\frac{1}{C_{ee}} + Q^j_{\tau^j}\frac{C_{qe}}{C_{ee}}\right) < 0, && (15)\\
E^i_{\tau^j} &= -\frac{1}{n-1}Q^{-j}_{\tau^j}\frac{C_{qe}}{C_{ee}} > 0 \qquad \forall i \neq j, && (16)\\
E_{\tau^j} &= -\left(\frac{1}{C_{ee}} + Q_{\tau^j}\frac{C_{qe}}{C_{ee}}\right) < 0. && (17)
\end{aligned}
$$

Correspondingly, the changes of the supplied quantities are given[12] by

$$
\begin{aligned}
Q^j_{\tau^j} &= -\frac{C_{qe}}{C_{ee}}\frac{1}{b}\frac{(n-1)a+b}{na+b} < 0, && (18)\\
Q^{-j}_{\tau^j} &= \frac{C_{qe}}{C_{ee}}\frac{1}{b}\frac{(n-1)a}{na+b} > 0, && (19)\\
Q_{\tau^j} &= -\frac{C_{qe}}{C_{ee}}\frac{1}{b}\frac{b}{na+b} < 0, && (20)
\end{aligned}
$$

where $a = P' + P''Q/n$ and $b = P' - det(Hess(C))$.

In the special case of identical firms facing equal local emission tax rates, the change of one single tax rate has analogous effects on emission and output levels. Although, an increase of τ^j induces all firms, except that of region j, to raise their emission and output levels, aggregate values decrease. Hence, supply and pollutant emissions move in the same direction.

3.2 Equilibrium of Interjurisdictional Tax Competition

The local regulator of region j maximizes the welfare of her residents, given by (5), s.t. the public budget constraint, $G^j = \tau^j E^j$, and the behavior of the local firms, given by (3) and (4). Differentiating the welfare function, $\mathcal{W}^j$, w.r.t. τ^j, gives

$$
\begin{aligned}
\mathcal{W}^j_{\tau^j} &= -q^j P' Q_{\tau^j} + U^j_g G^j_{\tau^j} + U^j_e E_{\tau^j} + \Pi^j_{\tau^j} + \Pi^j_{q^{-j}} Q^{-j}_{\tau^j}\\
&= U^j_e E_{\tau^j} + \left(U^j_g - 1\right) E^j + U^j_g \tau^j E^j_{\tau^j} - q^j P' Q_{\tau^j} + P' Q^j Q^{-j}_{\tau^j}. \qquad (21)
\end{aligned}
$$

[12]The results of REQUATE (1994) who considers a *single* regulator setting a uniform emission tax for all firms remain true in a more general framework with firms residing in different jurisdictions.

Setting its derivative equal to zero, and solving for τ^j yields

$$\tau^j = -\frac{U_e^j}{U_g^j}\left(1+\frac{E_{\tau^j}^{-j}}{E_{\tau^j}^j}\right)+\frac{1-U_g^j}{U_g^j}\frac{E^j}{E_{\tau^j}^j}+\frac{q^j}{U_g^j}\frac{P'}{E_{\tau^j}^j}Q_{\tau^j}-\frac{1}{U_g^j}\frac{P'}{E_{\tau^j}^j}Q^jQ_{\tau^j}^{-j} \quad (22)$$

$$= -\frac{U_e^j}{U_g^j}\left(1+\frac{E_{\tau^j}^{-j}}{E_{\tau^j}^j}\right)+\frac{1-U_g^j}{U_g^j}\frac{E^j}{E_{\tau^j}^j}-\frac{P'Q_{\tau^j}}{U_g^jE_{\tau^j}^j}(Q^j-q^j)+\frac{P'Q^jQ_{\tau^j}^j}{U_g^jE_{\tau^j}^j}. \quad (23)$$

Because every local government $j = 1, \ldots, n$ adjusts its tax rate according to (22), the resulting equation system determines the vector of equilibrium tax rates, i.e., the Nash equilibrium of interjurisdictional competition in tax rates.

The optimal emission tax consists of four parts: The first term of (22) (or (23)) reflects the fact that a rise of the local emission tax, τ^j, does not only alter local pollutant emissions, E^j, but also the pollutant emission of all non-resident firms. Hence, the local government has to evaluate the resulting *total* variation of E by multiplying marginal total emissions by its marginal social damage that emerges in region j. From (13) we know that $E_{\tau^j}^{-j} > 0$ and $E_{\tau^j}^j < 0$, so that the total emission reduction, $-E_{\tau^j}$, falls short of local reduction. Therefore, the bracket term of the first part is smaller than unity implying that the first part falls short of *local* marginal social damage of pollutant emissions (evaluated in terms of marginal utility of the local public good).

The second term of (22) (or (23)) stems from distortionary taxation. Since the tax basis, pollutant emissions, is under the control of private agents, increasing the local tax rate induces a production shift towards other regions. This widens the tax basis of other regions, ceteris paribus, resulting in a fiscal externality, for the other regional governments gain by increased public revenues. If the local regulator is endeavored to raise public funds through head taxes, this externality is evaded and public goods are provided at their efficient levels; i.e., the marginal rate of transformation between the private and the public good equals the marginal rate of substitution between these two goods, $U_g^j = 1$. In this case, the second term of (22) drops out. If, however, local public goods are underprovided, $U_g^j > 1$, the sign of the second term is positive (and vice versa). Underprovision[13] of public goods, and thus a relative scarcity of public funds, encourages a further increase of the emission tax, whereas, on the con-

[13]In fact, since the tax rate determines public revenues and spendings, the provision level of the public good is endogenous. Thus, it should be kept in mind that whether public goods are under- or overprovided is not exogenous but an endogenous matter of fact.

trary, overprovision discourages emission taxation. This fact is widely ignored by environmental literature.

The third term of (22) results from a change of local consumer surplus. Clearly, as we know from (12), a higher emission tax reduces total supply, and thus consumer surplus; this causes the third term to be negative.

Since residents hold all shares of the local firm and thus receive its full profits as dividend income, they completely bear local firm's costs resulting from a rise of the local emission tax. However, a more tightened tax-screw does not only affect local firm's behavior but also the behavior of non-resident firms. Therefore, this policy measure has a twofold impact on local residents dividend income, a *direct* and an *indirect* effect. The first one is given by $\Pi^j_{\tau^j} = -E^j < 0$; the latter, by $\Pi^j_{q^{-j}} Q^{-j}_{\tau^j} = P' Q^j Q^{-j}_{\tau^j} < 0$. An increase of the local emission tax has a positive effect on the supply of non-resident firms and therefore a negative effect on the market price. Hence, local firm's revenues and thus local consumers' dividend income decrease indirectly if the local regulator raises her emission tax.

Equivalently writing τ^j as given by (23) we get an alternative interpretation of the last two parts.[14] In this case, the third part results from change of local supply and demand; more precisely, the bracket term represents local excess supply. Thus, the local tax rate is the higher the higher the excess supply. If a region is a 'net-exporter', the third part causes the emissions tax to increase (and vice versa). In international economics this effect is called *terms-of-trade effect*. If no other effects are present, the equilibrium tax rate of a 'net-exporting' region exceeds local marginal damage. Hence, exclusively considering the terms-of-trade effect leads to the somehow ecologically 'euphoric' conclusion that interjurisdictional tax competition in emission taxes does not induce 'environmental dumping' for 'exporting' regions. However, it should be emphasized that this result, which was derived by KRUTILLA (1991) and PETHIG (1994), depends on some crucial assumptions: local public goods are efficiently provided, firms behave perfectly competitive, and there is no pollutant transmission. In the continuing analysis we argue under more general, i.e., more realistic, assumptions that local governments fix their emission tax rates rather too low than too high, even if local excess supply is present.

In the formulation of τ^j given by (23) the forth part stems from non-competitive behavior of the resident firm of region j. To see this, recall that

[14]This formulation is closely related to the commonly used presentation in the literature.

the forth part of (22) reflects the effect of the induced change of Q^{-j} on equilibrium price and thus on firm j's revenues. Since the non-competitive firm realizes its own impact on the equilibrium price and on its revenues, $P'Q^j dQ^j$ (see (3)), the welfare effect of τ^j on firm's revenues through Q^j drops out by envelope theorem. Thus, the remaining welfare effect, that has to be considered by the local regulator, results from the impact of the behavior of the other competitors on local firm's revenues through market price, given by $P'Q^jQ^{-j}_{\tau^j}$. If, on the other hand, firm j behaves perfectly competitive, the term $P'Q^jdQ^j$ is not considered by the firm, because it takes the output price as given. Therefore, the regulator additionally has to take into account this effect by also adding $P'Q^jQ^j_{\tau^j}$ to (21). In this case, the forth part of (23) resulting from non-competitive behavior of the local firm drops out.

Notice that as long as the local firm behaves non-competitively the sum of the third and the forth part is unambiguously negative, which can be seen by inspection of (22). If, however, we switch from non-competitive to competitive behavior of the firm, the local regulator has to consider the term $-P'Q^jQ^j_{\tau^j}/(U^j_g E^j_{\tau^j}) > 0$ in (22) additionally. Since this results in a change of the tax formula, the sign of the sum of the last two parts of (22) becomes ambiguous. Namely, as we see from (23), its sign exclusively depends on local excess supply.[15] However, here we deal with non-competitive firms whose behavior can be characterized as depicted in section 3.1.

From the last two parts we see that residents not only benefit but also suffer from a rise of τ^j through lower consumer surplus and lower dividend income. The local regulator weighs these welfare losses against the benefits resulting from an increase of the prevailing environmental quality and from an extension of the supply of the local public good. Altogether, the local emission tax rate is determined by one environmental term, one fiscal term, and two strategic terms. Note, however, that all welfare effects that accrue to non-residents – real (or technological) and pecuniary externalities – are ignored by the local regulator.[16]

Since the sum of the last two terms of (22) is negative, we get the following result for the case non-transboundary pollution:

[15]Evaluating (23) for a competitive firm at $U^j_g = 1$ we get the result of KRUTILLA (1991) and PETHIG (1994).

[16]We return to this point later on.

Proposition 3.1 *Assume that pollutant emissions are purely local. In Nash equilibrium the local emission tax exceeds (falls short of)* local *marginal environmental damage if and only if public funds are relatively scarce (not too scarce), in the sense that*

$$U_g^j - 1 \underset{(<)}{>} \frac{P'}{E^j}\left(q^j Q_{\tau^j} - Q^j Q_{\tau^j}^{-j}\right). \tag{24}$$

As long as resident's marginal utility of local public goods, evaluated at the equilibrium provision level, is not too high, the equilibrium tax rate is lower than local marginal damage. Only if in equilibrium public goods are underprovided to that large extents that U_g^j, i.e., the marginal value of public funds, is sufficiently high, the local government fixes τ^j above $-U_e^j/U_g^j$. The reason is that public funds are that scarce that the incentive to raise additional public revenues drives the local emission tax beyond local marginal damage of pollutants.

Even for the case of pollutant transmission we cannot rule out that emission taxes are set above local marginal damage. If the fiscal term is sufficiently high, $\tau^j > -U_e^j/U_g^j$ may occur, although pollution is not purely local. Hence, CONRAD'S (1993) result (p. 128), that under imperfect competition pollution taxes are set below local marginal damage, needs not to be true, though the opposite seems to be 'less likely'. Whether the local equilibrium tax rate is lower or higher than local marginal damage depends, among others, on the social value of public funds.

Note that, if the emission tax falls short of *local* marginal damage, it falls short of *nation-wide* marginal damage, all the more. Only if pollution is purely local, i.e., there is no pollutant transmission, local and nation-wide marginal social damage coincide.

Now consider the special case of identical regions. Assume that in all regions firms exhibit the same technologies and consumers have the same preferences, $U^j(\cdot) = U^i(\cdot) = U(\cdot)$, $p^j(\cdot) = p^i(\cdot)\ \forall i, j$. In this case, we have a symmetric Nash equilibrium of interjurisdictional tax competition in tax rates. To see this, we show that no region has an incentive to deviate unilaterally from $\tau^j = \tau^i\ \forall i, j$. Therefore, evaluate (21) at symmetric equilibrium tax rates, where $E^j = E/n$ and $q^j = Q^j = Q/n\ \forall j$,

$$\mathcal{W}_{\tau^j}^j = U_e E_{\tau^j} + (U_g - 1)\frac{E}{n} + U_g \tau^j E_{\tau^j}^j - \frac{Q}{n} P' Q_{\tau^j}^j. \tag{25}$$

Because, in this case, the tax rates affect aggregate values symmetrically, $Q_{\tau^j} = Q_{\tau^i}$, $E_{\tau^j} = E_{\tau^i}$, $Q^{-j}_{\tau^j} = Q^{-i}_{\tau^i}$, and $E^{-j}_{\tau^j} = E^{-i}_{\tau^i}$ $\forall i,j$, region j has no incentive to deviate unilaterally from $\tau^j = \tau^i \, \forall j,i$ if and only if region i has neither.

Solving (25) for τ^j yields the Nash tax rates of symmetric tax competition,

$$\tau^j = -\frac{U_e}{U_g}\frac{E_{\tau^j}}{E^j_{\tau^j}} + \frac{1-U_g}{U_g}\frac{E/n}{E^j_{\tau^j}} + \frac{P'Q/n}{U_g}\frac{Q^j_{\tau^j}}{E^j_{\tau^j}} \qquad \forall j. \tag{26}$$

For identical regions local excess supply equals to zero, i.e., there is no interregional trade and thus no terms-of-trade effect. In this case, the third part of (23) drops out, and the remaining strategic term stems from imperfect competition.

In the special case where all firms reside in region j, $E^{-j}_{\tau^j} = 0$ (and $Q^{-j}_{\tau^j} = 0$), and public goods are efficiently provided, we get EBERT'S (1992) result:[17]

$$\tau^j = -U_e + \frac{P'Q}{n}\frac{Q^j_{\tau^j}}{E^j_{\tau^j}} \qquad \forall j = 1, \ldots, n. \tag{27}$$

Note that for $n \longrightarrow \infty$, τ^j converges to the Pigouvian emission tax if pollution is purely local, i.e., there is no pollutant transmission causing a social damage in other regions. Thus, we have the following result:

Proposition 3.2 *If pollution is purely local, firms behave perfectly competitive, and the social value of public funds is equal to private marginal utility of income, interjurisdictional competition in emission tax rates is efficient; i.e., the equilibrium emission tax rates equal to the Pigouvian emission taxes.*

Proposition 3.2 states that interjurisdictional tax competition in emission taxes leads to efficiency only in a special limiting case. Since, in general, we have to expect inefficiency, this result is rather dis- than encouraging. It is well known that in order to re-establish efficiency we need as many policy tools as distortions exist. However, since in most real world's problems we are rather concerned about the determination of a *single* tax rate than of the whole tax system, efficiency, i.e., the first-best solution, is out of reach. In this case, instead of following a holistic approach, the appropriate policy advice is the incremental one that attempts to achieve a second-best allocation. To establish this, the best local governments can do is to determine their emission tax rates cooperatively, given their limited policy tools. Hence, in the next section we derive the cooperative emission tax

[17] REQUATE (1994) also considers a model of this kind, but the firms need not to be identical.

rates and compare them with their equilibrium values. This procedure allows us to reveal the incentives which make local governments to deviate from cooperative (second-best) solution.

3.3 Cooperative Behavior of Local Governments

In this section we derive those local tax rates that result from cooperative behavior of the local governments and contrast them with their equilibrium levels. Clearly, since due to the limited policy tools of each local government, the emission tax rate, efficiency is not attainable, the cooperative tax rates are only second-best.

If local governments behave cooperatively, they maximize the sum of all local welfare functions w.r.t. the emission taxes. Using the market clearing condition and substituting profit terms, given by (2), into (5) yields the cooperative maximization problem,

$$\max_{\vec{\tau}} \sum_{i=1}^{n} \mathcal{W}^i(\vec{\tau}) = \int_0^Q P(\xi)d\xi + \sum_{i=1}^{n} U^i(G^i, E) - \sum_{i=1}^{n} \left(C^i(Q^i, E^i) + \tau^i E^i\right). \quad (28)$$

Setting its derivatives equal to zero and rearranging terms yields

$$-P' \sum_{i=1}^{n} Q^i Q^i_{\tau^j} + \sum_{i=1}^{n} \tau^i U^i_g E^i_{\tau^j} + E_{\tau^j} \sum_{i=1}^{n} U^i_e - (1 - U^j_g)E^j = 0, \quad (29)$$

$\forall j = 1, \ldots, n.$

Let $\tilde{D}_e := -\sum_i U^i_e$, $R^i_{\tau^j} := P'(Q)Q^i Q^i_{\tau^j}$, and let $J\vec{E}(\vec{\tau})$ denote the Jacobian matrix of $\vec{E} := (E^1, \ldots, E^n)'$ evaluated at the second best tax rates. Additionally defining

$$\tilde{U}_g := \begin{bmatrix} U^1_g & & 0 \\ & \ddots & \\ 0 & & U^n_g \end{bmatrix} \quad \text{and} \quad \vec{R}_{\vec{\tau}} := \begin{bmatrix} \sum_i R^i_{\tau^1} \\ \vdots \\ \sum_i R^i_{\tau^n} \end{bmatrix},$$

we can write the equation system (29) in matrix notation as

$$-\vec{R}_{\vec{\tau}} - \left(I_n - \tilde{U}_g\right)\vec{E} + J\vec{E}(\vec{\tau})'\tilde{U}_g\vec{\tau} - \tilde{D}_e J\vec{E}(\vec{\tau})'\iota_n = 0, \quad (30)$$

where I_n denotes the identity matrix of rank n and $\iota_n := (1, \ldots, 1)'$. Solving (30) for $\vec{\tau}$ yields

$$\vec{\tau} = \tilde{U}_g^{-1}\left(\tilde{D}_e\,\iota_n + \left(J\vec{E}(\vec{\tau})'\right)^{-1}\left(\left(I_n - \tilde{U}_g\right)\vec{E} + \vec{R}_{\vec{\tau}}\right)\right), \quad (31)$$

For expository purpose, we mention the optimal cooperative tax rates (31) for the special case of two jurisdictions. In this case, the cooperative tax rate of region 1 is given by

$$\tau^1 = \frac{\tilde{D}_e}{U_g^1} + \frac{E^1 E^2_{\tau^2}(1-U_g^1) - E^2 E^2_{\tau^1}(1-U_g^2)}{U_g^1 det(J\vec{E}(\vec{\tau}))} + \frac{E^2_{\tau^2}\sum_i R^i_{\tau^1} - E^2_{\tau^1}\sum_i R^i_{\tau^2}}{U_g^1 det(J\vec{E}(\vec{\tau}))} \quad (32)$$

and correspondingly for τ^2.[18]

The optimal cooperative tax rates (31) consist of three additive terms. The first term, $-\sum_i U_e^i/U_g^j$, reflects social marginal damage of pollutant emissions in *all* jurisdictions, which is clearly higher than pure local social damage, $-U_e^j/U_g^j$. In addition, the marginal environmental damage is multiplied by *unity* in the cooperative tax rate formula, whereas it is multiplied by $1 + (E^{-j}_{\tau^j}/E^j_{\tau^j}) < 1$, in the equilibrium tax rate formula, (22). Thus, there are two effects which cause the equilibrium tax rates to fall short of social environmental damage associated with one additional unit of pollutant emission: first, the neglect of overall environmental damages, i.e., real externalities, resulting from local emissions; and second, the strategic effect of increased pollutant emissions in all other regions diminishing the benefit from local pollutant reduction through interregional pollutant transmission. Clearly, both effects are due to transboundary pollution and vanish if pollution is purely local. In the absence of transboundary pollution local and nation-wide marginal damage of pollutant emission coincide and equilibrium tax rates are efficient if no other effects are present.

In contrast to the (non-cooperative) equilibrium taxes, the (cooperative) second-best tax rates also take into account the fiscal externalities on public revenues of other jurisdictions, $J\vec{E}(\vec{\tau})'^{-1}(I_n - \tilde{U}_g)\vec{E}$. The direct increase of public revenues resulting from a raise of the emission tax, E^j, is multiplied by one minus the social value of public funds, $1 - U_g^j$, and weighted by the variation of local emissions, the inverse Jacobian matrix of E. Note that the sum of these effects may even be smaller than the single effect resulting from an increase of τ^j on the public revenues of region j, in general. Therefore, little can be said whether the fiscal terms of the equilibrium tax rates, given by the second parts of (22),

[18] For the special case where the marginal values of public funds are equal to unity, there is no pollutant transmission, $\tilde{D}_e = -U_e^j$, and all tax rates are necessarily the same, $\tau^j = \bar{\tau}\ \forall j$, i.e., all firms reside in one jurisdiction, the tax rates derived here reduce to the tax formula given by REQUATE (1994) (cf. equation (3.6)).

$\frac{1-U_g^j}{U_g^j}\frac{E^j}{E_{\tau^j}^j}$, fall short, equal, or exceed their cooperative, i.e., second-best, counterparts, given by $J\vec{E}(\vec{\tau})'^{-1}(I_n - \tilde{U}_g)\vec{E}$ of equation (31). Only for the special case of two regions, the comparison of the fiscal parts of the equilibrium and the second-best tax rates yields an unambiguous result. Especially, the deviations from the fiscal terms of the second-best tax rates are directly related to the fact whether we have under- or overprovision of local public goods.

Proposition 3.3 *In the special case of two regions, local governments fix their equilibrium tax rates (22) such that the fiscal terms fall short of their cooperative counterparts in (31) if in equilibrium we have underprovision of public goods in both jurisdictions; and exceed their cooperative counterparts if in equilibrium we have overprovision of public goods in both jurisdictions.*

Proof: W.l.o.g. consider the emission tax rate of region 1 and the corresponding fiscal terms, i.e., the second parts, of (22) and (31)/(32). Evaluated at the cooperative solution, the fiscal term of the Nash tax rate falls short of the fiscal term of the cooperative, i.e., second-best, tax rate if and only if

$$\frac{1-U_g^1}{U_g^1}\frac{E^1}{E_{\tau^1}^1} < \frac{1-U_g^1}{U_g^1}\frac{E^1}{E_{\tau^1}^1}\frac{E_{\tau^2}^2 E_{\tau^1}^1 - E_{\tau^1}^2 E_{\tau^1}^1 \frac{E^2}{E^1}\frac{1-U_g^2}{1-U_g^1}}{E_{\tau^1}^1 E_{\tau^2}^2 - E_{\tau^2}^1 E_{\tau^1}^2}. \qquad (33)$$

Rearranging terms we see that (33) is equivalent to

$$E_{\tau^2}^1 < E_{\tau^1}^1 \frac{E^2}{E^1}\frac{1-U_g^2}{1-U_g^1} \quad \text{for} \quad 1-U_g^1 > 0, \qquad (34)$$

$$E_{\tau^2}^1 > E_{\tau^1}^1 \frac{E^2}{E^1}\frac{1-U_g^2}{1-U_g^1} \quad \text{for} \quad 1-U_g^1 < 0. \qquad (35)$$

Because $E_{\tau^2}^1 > 0$ and $E_{\tau^1}^1 < 0$, (34) is always violated if $1-U_g^2 > 0$, and (35) is always fulfilled if $1-U_g^2 < 0$. Overprovision in both regions implies the reverse of (34); underprovision in both regions implies (35). Thus, if in equilibrium we have overprovision in both regions, the reverse of (33) is true, meaning that local governments fix the fiscal terms of their emission tax rates too high. If, on the contrary, we have underprovision in both regions, (33) is fulfilled, i.e., local governments fix their tax rates such that the fiscal terms fall short of their cooperative counterparts. This completes our proof of Proposition 3.3. #

Roughly speaking, Proposition 3.3 states that if, in the case of two jurisdictions, neither a strategic effect nor an external environmental damage effect is present, local governments fix their tax rates too low (high) if in equilibrium underprovision (overprovision) occurs. To put it the other way round, if in both regions the equilibrium public revenues fall short of those expenditures required to provide the efficient levels of public goods, equilibrium tax rates are fixed underneath their optimal cooperative levels (and vice versa). The intuition behind this is the following. Local governments do not consider the induced fiscal externalities resulting from determination of their tax rates. If one region enhances its emission tax, the emissions and thereby the tax revenues of the other region increase. Hence, the other region gains from this policy measure (in terms of public revenues) if local public goods are underprovided; but looses, if local public goods are overprovided.

However, in the hybrid case where we have underprovision in one and overprovision in the other region, little can be said, in general. The same is true if we have more than two jurisdictions.

Now we turn to the third part of the vector of the optimal, i.e., cooperative, emission taxes, (31). All fiscal effects, that accrue to local residents through their capital income from local firm's profits, are reflected by $J\vec{E}(\vec{\tau})'^{-1}\vec{R}_{\vec{\tau}}$. This term represents *all* cross-revenue effects resulting from the compound effects of output changes, $\sum_i P'(Q)Q^iQ^i_{\tau^j}$, and variations of emission demands, $J\vec{E}(\vec{\tau})$. The Nash taxes, however, are solely determined by the effect of a change of the local tax rate on local consumer surplus and their capital income.

For the case of identical regions, (31) reduces to a quite simple tax formula. By symmetry, we have

$$\vec{\tau} = \frac{\tilde{D}_e}{U_g}\iota_n + \frac{1}{U_g}\begin{bmatrix} E^j_{\tau^j} & & E^j_{\tau^i} \\ & \ddots & \\ E^j_{\tau^i} & & E^j_{\tau^j} \end{bmatrix}^{-1}\left((1-U_g)E^j\,\iota_n + \sum_i R^i_{\tau^j}\,\iota_n\right),$$

$$\Rightarrow \tau^j = -\frac{nU_e}{U_g} + \frac{1-U_g}{U_g}\frac{E/n}{E_{\tau^j}} + \frac{P'Q/n}{U_g}\frac{Q_{\tau^j}}{E_{\tau^j}}, \tag{36}$$

where we have used the fact that the determinant of a $n \times n$ matrix of type

$$\begin{bmatrix} a & & b \\ & \ddots & \\ b & & a \end{bmatrix}$$

is given by $(a-b)^{n-1}(a+(n-1)b)$ and that adding up the elements of any row of the corresponding complementary matrix[19] is equal to $(a-b)^{n-1}$.

In the symmetric case, the cooperative, i.e., second-best, emission tax rate reflects nation-wide marginal environmental damage of local pollutant emissions which is, due to (perfect) pollutant transmission, nothing but n times local marginal damage. Note that the factor of this term is no longer equal to $E_{\tau^j}/E^j_{\tau^j}$ – as it is the case in the formula of Nash tax rates, (26) – but unity, for the strategic term that takes into account the induced emission changes of non-resident firms drops out. Therefore, terms are no longer divided by partial derivatives of *local* but by those of *total* pollutant emissions. Since this is also true for the other terms, they are weighted by E_{τ^j}, not by $E^j_{\tau^j}$ as in (26). Correspondingly, the last part now considers non-competitive behavior of *all* firms (Q_{τ^j}), and not only of the local one ($Q^j_{\tau^j}$). Clearly, trade does not emerge between identical regions, and a terms-of-trade effect is neither present in the equilibrium, (26), nor in the optimal tax formula, (36).

3.4 The Sources of Inefficiency

In the preceding sections we have derived the equilibrium tax rates of interjurisdictional tax competition and their cooperative, i.e., second-best, levels. It was indicated that both do not coincide, in general, because local governments in determining emission taxes neglect the external effects of their policy measures. In this section we investigate the sources of this inefficiency of tax competition in detail, i.e., the reasons that make local governments to deviate from cooperative solution. To see how non-internalized effects distort second-best efficiency, we proceed as follows. First, for reasons of tractability, consider the case of identical regions. Afterwards, we turn to the general case of heterogeneous regions. To examine the unilateral incentive of jurisdiction j to deviate from cooperative solution, we evaluate $\mathcal{W}^j_{\tau^j}$, (21), at the vector of the cooperative tax rates, (implicitly) given by (36). For illustrative purpose, it is instructive to subtract $\partial \sum_i \mathcal{W}^i/\partial\tau^j$, given by (29); a quantity which is, evaluated at the cooperative tax rates, equal to zero. Canceling terms, this procedure yields for identical regions,

$$\mathcal{W}^j_{\tau^j} = -(n-1)U_e E_{\tau^j} - U_g \tau E^{-j}_{\tau^j} + \frac{Q}{n} P' Q^{-j}_{\tau^j}. \qquad (37)$$

[19]Let A denote a $n \times n$ matrix. The matrix $\tilde{A}$ is called complementary matrix of A if and only if $\tilde{A}A = A\tilde{A} = det(A)I_n$.

We see that three effects prompt local governments to deviate from cooperative tax rates: The first term represents the *external marginal environmental damages* resulting from the overall variation of industrial emissions. Clearly, the change of environmental damage in region j is already considered by the local government in determining τ^j. Since marginal environmental damage is the same in each region, external marginal damage is equal to $n-1$ times $-U_e$. It is illustrative to decompose the change of total emissions, E_{τ^j}, into $E^j_{\tau^j}$ and $E^{-j}_{\tau^j}$. Then, the total non-internalized external environmental damage consists of two parts: first, a change of local emissions directly affects the environmental quality of all other regions by *pollutant transmission*; second, a rise of τ^j induces an increase of the emissions of non-resident firms by $E^{-j}_{\tau^j}$ causing additional environmental damages. Following KENNEDY (1994), we call the latter effect *pollution shifting effect.*

The second source of inefficiency stems from non-internalized fiscal externalities represented by the second term. Although, pollution shifting causes environmental external damages, it also induces external benefits. The induced increase of the emissions of non-resident firms, $E^{-j}_{\tau^j}$, results in collection of additional public funds by other governments, given their tax rates. Multiplying these additional funds by its social price, U_g, gives the total external *fiscal effect.*

The third distorting effect stems from *production shifting.* A rise of the local emission tax, τ^j, not only affects the emissions but also the output quantities of the firms. Hence, consumer surplus and profits change in region j, but also in all other regions $i \neq j$. This impact of the local emission tax on the consumer surplus of non-residents and their profit income (dividends) are not considered by the government of jurisdiction j. The distortionary behavior of the local government is reflected by the third term of (37) which splits up (additively) into a *consumption* and a *profit effect* (or *capital income effect*). To see this, consider the effect of a change of τ^j on consumer surplus and profits of region i $(i \neq j)$,

$$\frac{\partial}{\partial \tau^j}\left[\int_0^{q^j} p^j(\nu)d\nu - P(Q)q^j. + \Pi^i(Q^i, E^i; Q^{-i}, \tau^i)\right] = -\frac{1}{n}P'QQ_{\tau^j} + P'Q^iQ^{-i}_{\tau^j}. \tag{38}$$

The first term of the right hand side, the change of consumer surplus, is negative, whereas the second term, the change of the profits, is positive, for $Q^{-i}_{\tau^j} = Q_{\tau^j} - Q^i_{\tau^j} < 0$. The intuition behind this is clear. Local residents suffer from a decrease of total supply implying a rise of the price, whereas the firm gains from this fact.

Summing up (38) over all $i \neq j$ yields for identical regions

$$-\sum_{i \neq j} \frac{1}{n} P'Q \left(Q^j_{\tau_j} + Q^{-j}_{\tau_j}\right) + \sum_{i \neq j} \frac{1}{n} P'Q \left(Q^j_{\tau_j} + (n-2)Q^i_{\tau_j}\right) \; = \; -\frac{Q}{n} P' Q^{-j}_{\tau_j}.$$

This proves our assertion that the third term of equation (37), the production shifting effect, is additively composed of a consumption and a profit effect.

Note that for the case of competitive firms the third term of (37) drops out, since the first term of (29) vanishes and in (21) the last two terms are replaced by $-q^j P' Q_{\tau_j} + P' Q^j Q_{\tau_j} = P'(Q^j - q^j) Q_{\tau_j}$.

Thus far, we have interpreted the single terms of (37) which determine the incentive for the government of jurisdiction j to deviate from the optimal, i.e., cooperative, tax rates; yet, the sign of $\mathcal{W}^j_{\tau_j}$ must be determined. By using (17) we see that the first term, stemming from *external marginal environmental damage*, is negative. From (16) we know that the second term, the *fiscal effect*, is also negative; and from (19) it is clear that the third distorting effect, the *production shifting effect*, is negative as well. Hence, all effects work in the same direction and the composed effect is obviously negative.

Proposition 3.4 *If all regions are identical and pollution is transboundary, each local government has an unambiguous incentive to deviate from cooperative solution by lowering its emission tax.*

If, however, there is no pollutant transmission, i.e., pollutants are purely local, the pollutant transmission effect vanishes; because no pollutant is transmitted, there are no direct external environmental effects of local emissions. In this case, each government already considers all environmental damages resulting from local pollutant emission. But, since the (negative) pollutant transmission effect drops out from (37), the incentive to deviate may become positive.

Corollary 3.1 *If all regions are identical, pollution is purely local, and firms behave perfectly competitive, local governments set their emission tax rates too low (high) if and only if local public goods are underprovided (overprovided) in equilibrium.*

Proof: To see this, rewrite (37) as

$$\mathcal{W}^j_{\tau_j} \;=\; -(n-1)U_e E^j_{\tau_j} + \big(-(n-1)U_e - \tau U_g\big) E^{-j}_{\tau_j} + \frac{Q}{n} P' Q^{-j}_{\tau_j}.$$

In the case of purely local pollution and perfectly competitive firms, the first and the third term of the right hand side drop out. Moreover, since each local pollutant emission of region $i \neq j$ does not cause any external damage, the incentive to deviate reduces to

$$\mathcal{W}^j_{\tau^j} = -(U_e + \tau U_g)\, E^{-j}_{\tau^j},$$

which is negative if and only if $\tau > -U_e/U_g$. However, from (26) we know that if local firms behave competitively, $\mathcal{W}^j_{\tau^j} < 0$ is equivalent to $1 - U_g < 0$. This completes our proof of Corollary 3.1. #

From Corollary 3.1 we see that the Nash equilibrium is efficient if pollution is purely local, firms behave perfectly competitive, and the equilibrium tax revenues exactly cover those expenditures that are necessary to provided public goods at their efficient levels. (See also Proposition 3.2.)

Besides, there is a second possibility that the Nash equilibrium coincides with the cooperative solution. If the firm residing in region j is sufficiently small, so that the production decisions of all other firms do not depend on Q^j, the local emission tax, τ^j, does not affect Q^{-j} and E^{-j}. Hence, if in the world of identical jurisdictions, pollution is purely local and firms do not have any market power, no region has an incentive to deviate from its cooperative tax rate.[20]

Note that the incentive to deviate from cooperative tax rates may be ambiguous if jurisdictions are not identical; although the same effects, as depicted above, are present. This is due to the fact that we are not able to weigh the single effects against each other. Consider local government's incentive to deviate from cooperative tax rates in the general case:

$$\mathcal{W}^j_{\tau^j} = -E_{\tau^j} \sum_{i \neq j} U^i_e - \sum_{i \neq j} U^i_g \tau^i E^i_{\tau^j} + P' \sum_{i \neq j} Q^i Q^i_{\tau^j} + (Q^j - q^j) P' Q_{\tau^j}. \quad (39)$$

From (39) we see that we cannot derive a result similar to Proposition 3.4 for heterogeneous jurisdictions, because we cannot uniquely determine the sign of the right hand side. The reason for this is twofold. First, for different regions, as we know from (14), the sign of E_{τ^j} may either be positive or negative; i.e., it is not ensured that the pollutant transmission effect which is negative dominates the positive pollution shifting effect. If the latter is sufficiently strong, the composed effect is positive, for non-resident firms extend pollutant emissions by more than

[20] KENNEDY (1994), p. 59, derives a similar result within a less general model.

the local firm reduces them. If this is the case, the external environmental effect provides some incentive to increase the emission tax.

Second, although the third term, which stems from non-competitive behavior of local firms, is negative, it is not quite clear whether the sum of the last two terms, the strategic terms, is negative as well. Since the last term depends on local excess supply, it is positive for 'exporting' and negative for 'importing' regions. Therefore, the sum of these strategic effects is negative for regions exhibiting local excess demand and ambiguous for regions with local excess supply.

For illustrative purpose we can alternatively decompose the last two terms of equation (39) as

$$P'\sum_{i\neq j} Q^i Q^i_{\tau j} + (Q^j - q^j)P'Q_{\tau j} = (Q - q^j)P'Q_{\tau j} + P'\sum_{i\neq j} Q^i Q^i_{\tau j} - P'Q^{-j}Q_{\tau j}.$$

This gives us a second access to means of interpretation. The last two terms of the right hand side represent the profit (or capital income) effect and are clearly negative; whereas, the first term, the consumption effect – the non-considered variation of consumer surplus, $(Q - q^j)P'Q_{\tau j}$, – is positive. Thus, again the sign of the sum of the last three terms, the production shifting effect, is ambiguous, in general. Without any simplifying assumptions we are not able to weigh both effects against each other.

Since the (negative) fiscal effect is always present, i.e., independent of whether we deal with identical regions or not, heterogeneous local governments face an additional incentive to deviate from the optimal (cooperative) solution by lowering the emission tax. Thus, even under perfect competition and without pollutant transmission 'exporting' regions may also tax emissions too low.

Note, however, that in an extreme case, because the external environmental damage effect as well as the production shifting effect may become positive, the incentive for a local government to deviate from cooperative solution, given by (39), *may* also become positive; i.e., the local government tends to deviate from cooperative solution by increasing its emission tax. If, for example, region j is so small that q^j/Q tends to be zero,[21] the production shifting effect is positive, if

[21] In this case, consumer surplus does not play any role, and the local regulator exclusively maximizes the sum of profits plus tax revenues minus environmental damage. Such an objective function is analyzed by Conrad (1993).

the market share of firm j is sufficiently large,

$$\frac{Q^j}{Q} > -\sum_{i \neq j} \frac{Q^i}{Q} \frac{Q^i_{\tau^j}}{Q_{\tau^j}}.$$

If local consumers dot not consume the considered item, $q^j = 0$, they are rather concerned about profit income than about consumer surplus. By neglecting the latter they prefer lower output quantities and higher profits. In the limiting case, they advocate monopoly quantities and prices to exploit non-resident consumers totally. Under these conditions – provided that the environmental as well as the fiscal effect are not too strong – the local regulator determines the emission tax too high rather than too low.

Nevertheless, provided that the external environmental effect is negative, not only excess demanding but also excess supplying regions tax emissions too low, as long as their 'trade surplus' is not too large. In other words, only the small group of those regions that exhibit a sufficiently large excess supply does not tax emission too low. This result rather supports than refuses the thesis that interjurisdictional tax competition leads to 'ecological dumping'.

3.5 Related Literature

From our analysis we see that the results of KRUTILLA (1991) and KENNEDY (1994) need not to be true any longer if we relax their simplifying assumptions. Our model is more general w.r.t. two main aspects. On the one hand, we do not assume that emissions (directly) depend on output, rather we allow that each firm determines its emissions independently.[22] On the other hand, we allow for inefficient provision of local public goods and include the effects of distortionary taxation, i.e., shifts in tax bases.

Within a framework of perfect competition and purely local pollution KRUTILLA (1991) (p. 132) states *"[...] the optimal environmental tax levy [the Nash tax] is greater than the standard Pigouvian tax if the regulating country is a net exporter, and less than the standard Pigouvian tax if the country is a net importer."* (In this sense see also PETHIG (1994).) However, by referring back to

[22]In fact, KENNEDY (1994) taxes output, because pollution is directly proportional to output. In this case, emission and output taxation are equivalent. (See also EBERT (1992).)

equation (23) we see that KRUTILLA'S result is only true if, in addition to perfect competition and purely local pollution, public goods are provided efficiently. But since we are essentially concerned about second-best analysis, the assumption that the marginal value of public funds equals the private marginal utility of income is inappropriate.

For the case of identical regions (and a symmetric equilibrium) KENNEDY (1994) (p. 59) makes a closely related statement *"[...] there is no net strategic effect under perfect competition with $\alpha = 0$ [no pollution shifting]. [...] the usual transboundary externality also vanishes when $\alpha = 0$, so the Nash equilibrium is efficient in this special case."* However, the analysis of our model shows that this result is only true for those jurisdictions which are sufficiently small. By inspection of (37), we see that local government's incentive to deviate from cooperative tax rates is negative, even though firms behave perfectly competitive and pollution is purely local. The reason is that a variation of the local tax rate creates fiscal externalities in any case. The fiscal term of (37) only vanishes if region j is sufficiently small, such that local policy does not affect equilibrium values of the output market. In this case, we have $Q^i_{\tau^j} = 0$, $E^i_{\tau^j} = 0$, $\forall i \neq j$, and $dp/d\tau^j = 0$. and local government's incentive to deviate from efficiency is given by $-(n-1)E^j_{\tau^j}U^j_e < 0$ if we have perfect pollutant transmission and is equal to zero if pollution is purely local.[23]

4 Concluding Remarks

We have elaborated a partial model of interjurisdictional tax competition encompassing environmental aspects and the provision of a local public good. Each local government, exhibiting Nash behavior, has to determine it emission tax rate which serves the threefold purpose of raising public funds, regulating emissions, and affecting the output market. The resulting equilibrium tax rates are contrasted with their cooperative, i.e., second-best, levels. We have identified three main effects that cause each local equilibrium tax rate to differ from efficiency: First, the external environmental damage effect composed of the pollution transmission and the pollution shifting effect. The former stems from diffusion of local pollutants; the latter, from increased emissions of non-resident firms. Second, the

[23]Alternatively, we may examine the Nash tax rates (26) with their cooperative levels (36). (See also Proposition 3.1.)

fiscal effect on public revenues and provision levels of the public good of other jurisdictions. Third, each variation of a local emission tax affects the equilibrium of the whole output market and induces an interregional production shift. This effect can be split up either in a change of consumer surplus and of consumers' profit (i.e., dividend) income or in an imperfect competition and a terms-of-trade effect.

Although it is often stated that in equilibrium of interjurisdictional tax competition emission taxes on pollutant emissions of non-competitive local firms fall even short of local marginal environmental damage, this need not to be true, in general. If in equilibrium public funds are sufficiently scarce, i.e., public goods are underprovided to large extents, the emission tax exceeds local marginal environmental damage. However, we have shown that if, in the case of two jurisdictions, neither a strategic effect nor an external environmental damage effect is present, local governments fix their tax rates too low (high) if in equilibrium underprovision (overprovision) occurs in both regions.

Beyond this, if regions are identical, local governments have an incentive to deviate from cooperative solution (second-best tax rates) by lowering their tax rates. However, in the general case of heterogeneous jurisdictions, we cannot exclude the possibility that some local governments attempt to deviate by increasing their tax rates. Especially, this may be the case if the local government is little concerned about consumer surplus and if nation-wide emissions increase as the local tax rate is enhanced. Nevertheless, it should be stressed that a positive incentive to deviate seems to be a more or less pathological case, for the fiscal effect gives local governments strong incentives to fix their tax rates too low, rather than too high. Namely, the result found in the case of identical jurisdictions suggests that, as long as competing jurisdictions are not too different, every region attempts to undercut its cooperative tax rate. This gives us reasons to (weakly) support the thesis that interjurisdictional tax competition leads to 'ecological dumping'.

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