STRATEGIC ENVIRONMENTAL TAXATION IN THE PRESENCE OF INVOLUNTARY UNEMPLOYMENT AND ENDOGENOUS LOCATION CHOICE

Susanne Pech*)
Michael Pfaffermayr)**

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*) Department of Economics
University of Linz
A-4040 Linz - Auhof
Austria
Tel.: ++43-732-2468-593
Fax: ++43-732-2468-9821
e-mail: susanne.pech@jk.uni-linz.ac.at

**) WIFO - Austrian Institute
of Economic Reseach
P.O. Box 91
A-1103 Vienna
Austria
Tel.: ++43-222-7982601-253
Fax: ++43-222-7989386
e-mail: pfafferm@wsr.ac.at

Correspondance

Please, address all correspondance to Susanne Pech.

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Abstract

We analyze strategic environmental taxation in a two-country model with local environmental pollution. Two firms decide whether to serve the foreign market either by exports from the domestic plant or by operating a subsidiary in the foreign country. When involuntary unemployment prevails, a conflict in two policy goals arises: One the one hand countries want to internalize the negative externalities due to pollution in production. On the other hand they try to fight unemployment by inducing the foreign firm to immigrate by means of low environmental taxes. We identify two non cooperative equilibria depending on the magnitude of the marginal disutility of pollution and of the firms' mobility: Either countries are content with one plant within their bounderies or, alternatively, interjurisdictional competition results in two plants in each country. Whether the latter equilibrium induces welfare losses for both countries, depends again on the parameter values. This result is in contrast to previous studies, which neglected labour market effects.

Keywords: Environmental taxation; Tax competition; Plant location; Involuntary unemployment

JEL-classification: H73; Q20; R32.

1. Introduction

According to textbooks, environmental pollution stemming from the production of goods can easily be overcome by measures which lead to an internalization of external costs, e.g. by a Pigouvian tax. However, in open economies which face high and persistent involuntary unemployment and mobile capital, these measures might be not implemented because the policy makers worry that stricter environmental policies would cause even higher unemployment. The argument usually goes as follows: If one country designed an appropriate environmental policy, while the other countries kept up their lax environmental standards, this would make production solely within its boundaries more costly. Domestic firms would lose market shares and - more important - would migrate abroad. Higher involuntary unemployment would be the consequence. If this argument is correct and governments in fact trade off environmental quality against employment, countries might be in a prisoners' dilemma situation with inefficiently low environmental taxes or standards and excessive environmental deterioration for all countries. This line of reasoning lies behind the call for international cooperation, specifically in harmonized standards for environmental quality in the European Union, even in the case of local environmental damage (without spill over effects to other member states) to avoid this "destructive“ interjurisdictional competition.

The question whether such a destructive interjurisdictional competition may indeed occur, was addressed in various contributions. Cumberland (1981), Oates and Schwab (1988, 1996), Long and Siebert (1991), Wellisch (1993) showed that in a first best world with perfect product and factor markets the efficient environmental policy is realized. But whenever the governments have no access to the adequate policy instruments and/or there is some scope for strategic behaviour, interjurisdictional competition will result in inefficient outcomes[1]. The first papers that made use of a game-theoretic approach were Motta and Thisse (1994) as well as Markusen, Morey and Olewiler (1993) in the context of imperfect competition in the product market and endogenous location choice. They investigated how a variation of the environmental tax by one country influences the location decisions of an international duopoly and the country's welfare under the assumption that the foreign country does not react.

Markusen, Morey and Olewiler (1995), Rauscher (1995) and Hoel (1997) are some of the few studies that emphasize the strategic interactions among the environmental policy decisions in competing jurisdictions and thus are of special interest. They investigate environmental taxation, when there is a multinational monopoly in the product market. Depending on the marginal damage due to polluting production the jurisdictions set the taxes too low in order to attract the firm and end up in a situation with inefficient environmental taxes and welfare losses for all countries.

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[1] See Oates (1997) for detailed discussion of the two contrary results and the underlying assumptions of the models.

Markusen et al. and Rauscher neglect the effects of environmental taxation on the labour market[2]. The welfare change in a country is only determined by the change in consumer surplus, in tax revenues and environmental damage. As a consequence both models do not allow the governments to trade-off labour income against environmental quality. Hoel varies his original model which also neglects labour market effects by including a positive employment effect in the welfare function. He compares the results of both models and shows that the qualitative conclusions remain more or less unchanged.

The purpose of our work is to overcome the draw back of most of the previous studies and to address attention to environmental policy in the presence of involuntary unemployment. We model an imperfect labour market by introducing rigid wage rates above the market clearing level[3]. We assume that labour subsidies that remove the resulting disequilibrium are not available for the governments, as it is observed in reality. Hence, a conflict in the two policy goals arises: On the one hand countries want to internalize negative externalities due to environmental damage in production. On the other hand they try to fight unemployment by inducing foreign firms to immigrate via low environmental taxes or standards.

We consider endogenous location choice and Cournot competition in an international duopoly. Pollution is generated as a by-product. But the pollution in one country does not cause spill-over effects to the other country. The firms are assumed to be already established in their respective country of origin at the beginning[4]. There are two possibilities for each firm to serve the foreign market: Either by exports from its domestic plant or by establishing a subsidiary in the foreign country[5]. Export production causes higher marginal costs because of transportation, but it saves the fixed set-up costs of the new plant in the other country. In deciding what to do, each firm considers these two kinds of costs as well as the difference in the level of the environmental taxes in both countries. By undercutting the other country's environmental tax, each government is able to give an incentive to the foreign firm to establish a subsidiary in its country or to induce the domestic firm to forgo building a plant in the foreign country.

The interjurisdictional competition is modeled in a three stage non-cooperative game with complete and imperfect information. In the first stage both governments impose their

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2 Rauscher does not model a labour market at all, while Markusen et al. assume a clearing labour market. The competitive sector that produces a clean good with a linear technology, determines the constant wage level of the economy. Although labour income is included in the welfare function, it is constant, as the clean sector will completely absorb the dismissed workers in case of lower production in the dirty sector.

3 Bovenberg/van der Ploeg (1996) also choose this simple version of an imperfect labour market to investigate the robustness of the double-dividend results to the introduction of involuntary unemployment.

4 Motta/Thisse (1994) choose the same approach to express their belief that firms are linked by historical, cultural and economic reasons to their home country.

5 Besides, of course, firms are free to refrain from serving the foreign market. But they do not consider the total shut-down of the plant in the home country and serving both markets from the new plant in the foreign country. This can be justified either by sufficiently high set up costs for transferring total production abroad or by sufficiently high firm specific sunk costs.

environmental taxes simultaneously. Each government's decision criterion is to maximize the welfare of its country. It takes into account that the environmental tax determines not only the level of disutility from pollution, the level of tax revenues and the consumer surplus[6], but also the location decisions of the firms and, as a consequence, the level of involuntary unemployment. In the second stage of the game, the two firms observe the imposed taxes and fix their location plans simultaneously. In the third stage of the game they choose the level of production and sales simultaneously on the basis of a Cournot game. As usual, the game is solved by the method of backward induction.

In this framework we analyze whether governments are content with the initial firms' location decision of one plant in each country or whether interjurisdictional competition results in additional plants. We will show that both types of symmetric non cooperative equilibria are possible, depending on the values of the exogenous parameters. The first equilibrium is characterized by tax rates that induce each firm to serve the foreign market by exports. It is realized, if the marginal disutility of pollution is quite high and firms are rather immobile. We identify a second equilibrium, in which each government imposes a lower tax rate that induces both firms to operate a foreign subsidiary. This interjurisdictional competition resulting in two plants in each country takes place at lower values of marginal disutiliy of pollution and greater mobility of the firms. Further, we find the following welfare implications: Whether the second equilibrium, characterized by two plants in each country, induces welfare losses for both countries, depends again on the parameter values. It follows that interjurisdictional competition for plants by means of environmental taxes need not be destructive in the presence of involuntary unemployment and strategic policy makers. This result is in contrast to previous studies, which neglected labour market effects.

This paper is organized as follows: The next section introduces the model. In section 3 we derive the two non cooperative equilibria and analyze the supporting range of parameter values for each. Section 4 deals with the welfare analyses. The last section concludes.

2. The model

We assume two identical countries and two identical firms. This and the following assumptions about technology, preferences and welfare help us to obtain manageable expressions for the solutions of the game. The polluting good x is produced according to the linear technology

(1) $$x = \beta L^X ,$$

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6 However, we leave the producer surplus out in the welfare function. This can be explained by the fact that the ownership of the firm is widely distributed throughout the world so that the firm's profits do not remain in the country (Markusen et al., 1995).

where L^x denotes the amount of labour used for the production of good x.

The quasilinear preferences of a representative individual of country j = H, F (H denotes home, F foreign) can be expressed by the utility function[7]

(2) $$U_j = aC_j^x - \tfrac{1}{2}(C_j^x)^2 + C_j^y - d\,x_j .$$

Utility depends on C_j^x, the consumption level of the „dirty“ good x, on C_j^y, the money value of consumption of all „clean“ goods y ≠ x, and on d x_j, the environmental damage. This term consists of a constant marginal disutility of pollution (d) and the total output of the polluting sector x in country j (x_j).

The environmental tax t_j is levied on the production amount of good x in country j. The population of country j consists of B_j individuals. If the tax revenues are redistributed equally on all B_j individuals, the budget constraint of an individual is given by

(3) $$p_j^x C_j^x + C_j^y = \overline{w}L_j + \frac{t_j x_j}{B_j} .$$

p_j^x denotes the price of good x in country j and $\overline{w}$ denotes the rigid and too high wage rate[8] per unit of employed labour L_j. (3) states that consumption expenditures on the x- and y-goods must be equal the labour income and the lump sum transfer. For simplicity, we normalize the population to B_j = 1. Maximizing (2) subject to (3) yields the linear demand function for good x in each country j

(4) $$p_j^x = a - C_j^x ,$$

whereby the parameter „a“ can be interpreted as the market size in country j.

Firms' behaviour: The Cournot quantity setting duopoly is faced with the demand functions (4) and decides about location and quantities of the good sold in both countries. Each firm is already located in its home country and decides whether to serve the foreign market either by exports or from a subsidiary in the foreign country or to refrain from serving the foreign market. In this section we describe these plant configurations and the corresponding equilibrium quantities. We denote the equilibrium quantities of firm j sold in countries j and k by x_{jj} and x_{jk} and accordingly the supply quantities of firm k in country j and k by x_{kj} and x_{kk}. The comparison

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7 Following Markusen et al. (1995).

8 Wage rigidity can be justified by the theory of efficiency wages adapting the rudimentary model by Stiglitz(1976). Each firm's production function can be modified to $x_j = \beta(w)L_j^x$, where β can be interpreted as the efficiency of labour, depending on the wage rate w. Firms will offer a wage $\overline{w}$ that minimizes labour costs per efficiency unit and satisfies the condition $\frac{\partial\beta(\overline{w})}{\partial w}\cdot\frac{\overline{w}}{\beta(\overline{w})} = 1$. As a consequence, changes in the product market equilibrium will only change labour demand, but not the efficiency wage.

of a firm's profits at the different locations will give us a handy way to talk about the locations decisions for later use. Actually, we will show in Lemma 1 that the location decision of a firm is independent of the other firm's location.

In the first configuration, denoted by (P_j^1, P_k^1), each firm has a plant in its mother country and serves the foreign market by exports. As the plant-specific fixed costs are sunk for the plant already established in the home country, each firm j has constant average and marginal costs $\left(\overline{w}/ß + t_j\right)$ for units produced for the home market j and $\left(\overline{w}/ß + t_j + s\right)$ for units produced for the foreign market k, where s denotes the constant marginal transportation costs. The term $\overline{w}/ß$ will be abbreviated with b in the following. In the symmetric Nash-Cournot equilibrium for the configuration (P_j^1, P_k^1), $j \neq k$[9], output quantities of firm j and k are

in market j: (5a) $x_{jj} = \frac{1}{3}(a - b + s - 2t_j + t_k)$ (5b) $x_{kj} = \frac{1}{3}(a - b - 2s + t_j - 2t_k)$,

in market k: (5c) $x_{jk} = \frac{1}{3}(a - b - 2s - 2t_j + t_k)$ (5d) $x_{kk} = \frac{1}{3}(a - b + s + t_j - 2t_k)$.

and the total equilibrium profits earned by firm j are

(6) $$\pi_j(P_j^1, P_k^1) = x_{jj}^{\;2} + x_{jk}^{\;2} = \tfrac{1}{9}\left(a - b + s - 2t_j + t_k\right)^2 + \tfrac{1}{9}\left(a - b - 2s - 2t_j + t_k\right)^2 .$$

The symmetric plant location (P_j^2, P_k^2), $j \neq k$, describes the case, where each firm operates a plant in the domestic and in the foreign country, so there is no trade. Each firm incurs fixed costs g for setting up the subsidiary, but no transportation costs. The equilibrium quantities of firm j and k[10] are

in market j: (7a) $x_{jj} = \frac{1}{3}(a - b - t_j)$ (7b) $x_{kj} = \frac{1}{3}(a - b - t_j)$,

in market k: (7c) $x_{jk} = \frac{1}{3}(a - b - t_k)$ (7d) $x_{kk} = \frac{1}{3}(a - b - t_k)$

and the corresponding total profits of firm j

(8) $$\pi_j(P_j^2, P_k^2) = x_{jj}^2 + x_{jk}^2 - g = \tfrac{1}{9}\left(a - b - t_j\right)^2 + \tfrac{1}{9}\left(a - b - t_k\right)^2 - g .$$

In the case of the asymmetric plant configuration (P_j^2, P_k^1), firm j operates a plant in the home country as well as in the foreign country, while firm k produces only in its home country k and serves country j by exporting. Equilibrium outputs in market j are given by (5a) and (5b) and in market k by (7c) and (7d). Total equilibrium profits earned by firm j are

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9 The profit function of firm j is $\pi_j = (a - C_j^x)x_{jj} + (a - C_k^x)x_{jk} - (b + t_j)x_{jj} - (b + t_j + s)x_{jk}$, $j \neq k$, where C_j^x consists of x_{jj} and x_{kj} and C_k^x of x_{kk} and x_{jk}. Differentiating π_j with respect to x_{jj} and x_{jk} gives the reaction curves of firm j on market j and k, showing the profit maximizing output quantities on each market for any given output quantity of the firm k on the respective market. The intersection of the reaction curves of both firms on each market j and k marks the Cournot non cooperative equilibrium outputs. Since the algebra of this standard Cournot model is well known, we report only the equilibrium outputs and profits in the following.

10 The profit function of firm j is $\pi_j = (a - C_j^x)x_{jj} + (a - C_k^x)x_{jk} - (b + t_j)x_{jj} - (b + t_k)x_{jk} - g$, $j \neq k$. The equilibrium outputs are calculated in the same manner as in the case of (P_j^1, P_k^1).

(9) $$\pi_j(P_j^2, P_k^1) = x_{jj}^2 + x_{jk}^2 - g = \tfrac{1}{9}\left(a - b + s - 2t_j + t_k\right)^2 + \tfrac{1}{9}\left(a - b - t_k\right)^2 - g\,.$$

The reverse case, where firm k operates one plant in each country, while firm j serves market k by exports, is denoted by (P_j^1, P_k^2). At this plant configuration, equilibrium outputs in market j are given by (7a) and (7b) and in market k by (5c) and (5d). The equilibrium profits of firm j are

(10) $$\pi_j(P_j^1, P_k^2) = x_{jj}^2 + x_{jk}^2 = \tfrac{1}{9}\left(a - b - t_j\right)^2 + \tfrac{1}{9}\left(a - b - 2s - 2t_j + t_k\right)^2.$$

Finally we consider a firm's choice to refrain from serving the foreign market. At the plant configuration $(P_j^{1^{ne}}, P_k^1)$ each firm has one plant in the home country. While firm k exports, firm j supplies only the home market j, but not the foreign market k (indicated by "ne", which stands for "no exports"). Consequently, firm k is a monopoly in market k. Equilibrium outputs in market j are given by (5a) and (5b) and in market k by

(11a) $x_{jk} = 0$ (11b) $x_{kk} = \tfrac{1}{2}(a - b - t_k)$.

Total equilibrium profits earned by firm j are

(12) $$\pi_j(P_j^{1^{ne}}, P_k^1) = x_{jj}^2 = \tfrac{1}{9}\left(a - b + s - 2t_j + t_k\right)^2.$$

The reverse case, where firm k refrains from serving the foreign market j, while firm j supplies country k by exports, is denoted by $(P_j^1, P_k^{1^{ne}})$. Thus firm j has monopoly power in home market j. Equilibrium outputs are

(13a) $x_{jj} = \tfrac{1}{2}(a - b - t_j)$ (13b) $x_{kj} = 0$.

in market j and (5c) and (5d) in market k. Total profits of firm j are given by

(14) $$\pi_j(P_j^1, P_k^{1^{ne}}) = x_{jj}^2 + x_{jk}^2 = \tfrac{1}{4}\left(a - b - t_j\right)^2 + \tfrac{1}{9}\left(a - b - 2s - 2t_j + 2t_k\right)^2.$$

Finally we describe the plant configurations, at which one firm does not serve the foreign market, while the other firm operates one plant in each country. Thus, again there is no trade. At $(P_j^{1^{ne}}, P_k^2)$ both firms operate a plant in country j, thus outputs in market j are given by (7a) and (7b). As firm j does not supply the foreign market k, firm k is a monopoly in market k and equilibrium outputs are (11a) and (11b). Total equilibrium profits of firm j are

(15) $$\pi_j(P_j^{1^{ne}}, P_k^2) = x_{jj}^2 = \tfrac{1}{9}\left(a - b - t_j\right)^2.$$

The reverse case, where firm k refrains from serving the foreign market j, while firm j operates a subsidiary in country k, is denoted by $(P_j^2, P_k^{1^{ne}})$. At this plant configuration, equilibrium outputs are (13a) and (13b) in market j and (7c) and (7d) in market k. Total profits of firm j are

(16) $$\pi_j(P_j^2, P_k^{1^{ne}}) = x_{jj}^2 + x_{jk}^2 - g = \tfrac{1}{4}\left(a - b - t_j\right)^2 + \tfrac{1}{9}\left(a - b - t_k\right)^2 - g\,.$$

For a given pair of tax rates (t_j, t_k), each firm will choose the location that maximizes its profits at the second stage of the game. For later use, we formulate

Lemma 1: *The location decision of firm j is independent of the location decision of firm k.*

Proof: The difference in firm j's profits between

i) operating two plants and operating one plant with export production, denoted by $\Delta\pi_j^{2\to1}$,

ii) operating two plants and operating one plant without export production, denoted by $\Delta\pi_j^{2\to1^{ne}}$,

iii) operating one plant with export production and operating one plant without export production, denoted by $\Delta\pi_j^{1\to1^{ne}}$,

is independent of the location and production decision of firm k.

i) Using (9), (6), (8), (10), (16) and (14), this assertion follows from

$$\text{(17)}\quad \Delta\pi_j^{2\to1} := \pi_j(P_j^2, P_k^1) - \pi_j(P_j^1, P_k^1) = \pi_j(P_j^2, P_k^2) - \pi_j(P_j^1, P_k^2) = \pi_j(P_j^2, P_k^{1^{ne}}) - \pi_j(P_j^1, P_k^{1^{ne}})$$
$$= \tfrac{1}{9}(a - b - t_k)^2 - \tfrac{1}{9}(a - b - 2s - 2t_j + t_k)^2 - g .$$

ii) Using (9), (12), (8), (15), (16) and $\pi_j(P_j^{1^{ne}}, P_k^{1^{ne}}) = \tfrac{1}{4}(a - b - t_j)^2$, this follows from

$$\text{(18)}\quad \Delta\pi_j^{2\to1^{ne}} := \pi_j(P_j^2, P_k^1) - \pi_j(P_j^{1^{ne}}, P_k^1) = \pi_j(P_j^2, P_k^2) - \pi_j(P_j^{1^{ne}}, P_k^2) = \pi_j(P_j^2, P_k^{1^{ne}}) - \pi_j(P_j^{1^{ne}}, P_k^{1^{ne}})$$
$$= \tfrac{1}{9}(a - b - t_k)^2 - g .$$

iii) Using (6), (12), (10), (15), (14) and $\pi_j(P_j^{1^{ne}}, P_k^{1^{ne}}) = \tfrac{1}{4}(a - b - t_j)^2$, this follows from

$$\text{(19)}\quad \Delta\pi_j^{1\to1^{ne}} := \pi_j(P_j^1, P_k^1) - \pi_j(P_j^{1^{ne}}, P_k^1) = \pi_j(P_j^1, P_k^2) - \pi_j(P_j^{1^{ne}}, P_k^2) = \pi_j(P_j^1, P_k^{1^{ne}}) - \pi_j(P_j^{1^{ne}}, P_k^{1^{ne}})$$
$$= \tfrac{1}{9}(a - b - 2s - 2t_j + t_k)^2$$

Clearly, firm j has positive export profits ($\Delta\pi_j^{1\to1^{ne}} > 0$), if $a - b - 2s - 2t_j + t_k > 0$, while it is not profitable for firm j to export, if $a - b - 2s - 2t_j + t_k \le 0$. QED.

Due to Lemma 1, firm j decides to establish a subsidiary in the foreign country k, if $\Delta\pi_j^{2\to1} \ge 0$ and $\Delta\pi_j^{2\to1^{ne}} \ge 0$. This is more likely, the lower the set up costs of the subsidiary, the higher the transportation costs and the lower the tax rate of the foreign country k compared to the tax rate of the home country j. On the other hand, firm j decides for export production, if $\Delta\pi_j^{2\to1} < 0$ and $\Delta\pi_j^{1\to1^{ne}} > 0$, and decides not to serve the foreign market, if $\Delta\pi_j^{2\to1^{ne}} \le 0$ and $\Delta\pi_j^{1\to1^{ne}} \le 0$.

Governments' behaviour: Total employment L_j consists of L_j^x and L_j^y, the labour employed in sector x and in sector y respectively. We assume that the workers' skills are sector specific, at least in the short run, hence the other clean sector y cannot absorb dismissed workers in case of lower production in the polluting sector x. Therefore the government regards L_j^y as constant. By substituting the budget constraint (3), the demand function (4) and production function (1) into the utility function (2), the social welfare function takes the form

$$\text{(20)}\qquad W_j = \tfrac{1}{2}\left(C_j^x\right)^2 + \left(\tfrac{\overline{w}}{\beta} + t_j - d\right)x_j + \overline{w}\overline{L}_j^y .$$

The first term of the welfare function represents the consumer surplus due to good x. The second term is composed of labour income in the x-sector $\left(\overline{w}/ß\right)x_j = \overline{w}L_j^x$, the revenues of the environmental tax $t_j x_j$ and the disutility of pollution d x_j. Clearly, labour income is the higher, the higher the level of output (and of employment). So, in the presence of a rigid and too high wage rate causing involuntary unemployment, governments care about the effects of environmental taxation on the employment level. The third term $\overline{w}\overline{L}_j^y$ describes constant labour income in the y-sector, corresponding to the assumption that there are no effects of the environmental tax on the clean sector y.

We assume that governments have complete information about firms' behaviour. When choosing t_j in order to maximize (20)[11], each government takes the tax rate of the other country as given. The firms' discrete location choices cause discontinuities of the tax reaction and the welfare functions of the countries. For example, consider a pair of tax rates that induce the location choice (P_j^1, P_k^1). Country j can induce the domestic firm to give up export production (either (P_j^2, P_k^1) or $(P_j^{1^{ne}}, P_k^1)$ emerges), if it raises its tax rate above a critical value, given the tax rate of the other country. In both cases it looses the export production and thus employment and consumer surplus, but avoids environmental damage[12]. By reducing its tax rate below a critical level, it gives the foreign firm k an incentive to give up export production. Depending on the extent of the tax cut, firm k decides either to supply market j from a subsidiary in country j or to refrain from serving market j. In the first case (P_j^1, P_k^2), country j gains a second plant and thereby employment and consumer surplus, but also more pollution. In the second case $(P_j^1, P_k^{1^{ne}})$, country j helps firm j to monopoly power and thereby gains employment, but suffers from higher pollution levels and a loss in consumer surplus.

3. Two non cooperative equilibria

In this section we analyze whether governments compete for more plants or whether they are content with the initial plant configuration (P_j^1, P_k^1). We will show that both types of symmetric non cooperative equilibria are possible, depending on the values of the exogenous parameters.

3.1 No establishment of subsidiaries as a result of interjurisdictional competition

The case of immobile firms and high marginal environmental damage

This non cooperative equilibrium is characterized by tax rates that do not change the initial plant configuration (P_j^1, P_k^1). Hence, competition among the countries does not result in an

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[11] This approach leads to a „second best" solution, as only one instrument, the environmental tax, is used for the correction of (i) the externality caused by pollution, (ii) imperfect competition on the good market and (iii) wage rigidity on the labour market.

[12] As the tax rate rises and the output level decreases, the change of tax revenues may be positive or negative.

attraction of a second plant. This will be the case at parameter values that impede firms' mobility and at rather high values of environmental damage. To characterize the subgame perfect equilibrium, abbreviated by [$t_j^*, t_k^*, (P_j^1, P_k^1)$], we will proceed as follows:

a) (i) We calculate the tax rates t_j^*, t_k^* that constitute a Nash equilibrium at the first stage of the game, assuming the plant location (P_j^1, P_k^1) with exporting as given.

(ii) As firms choose their locations endogenously, we have to ensure that in the second stage firms indeed choose location (P_j^1, P_k^1), given governments impose t_j^*, t_k^*, i. e. each firm decides for exporting against operating a foreign subsidiary as well as against refraining from serving the foreign market. This gives us the conditions NOS* and PEP*.

By step a), we made sure, that each government j has no incentive to deviate from t_j^* to any other tax rate that maintains firms' location decision (P_j^1, P_k^1), given t_k^*.

b) But as governments can change the firms' location decision by an appropriate unilateral change in the tax level, we have to formulate conditions guaranteeing that governments do not deviate from t_j^*, t_k^* considering all possible location decisions of the firms. Because of the discontinuities of the countries' tax reaction curves due to firms' discrete location choices, this requires complex analysis, which will be done in two parts:

(i) We show (in Lemma 2) that given the firms' location choice (P_j^1, P_k^1) at t_j^*, t_k^*,

- a sufficiently large unilateral tax cut by country j induces the foreign firm k to give up export production. Depending on the extent of the tax cut, firm k decides either to refrain from serving market j (configuration $(P_j^1, P_k^{1^{ne}})$) or to serve market j from a subsidiary in country j (configuration (P_j^1, P_k^2)).
- a sufficiently large unilateral tax raise by country j induces firm j to give up exporting. Depending on the level of t_k^*, firm j operates a subsidiary in country k instead (configuration (P_j^2, P_k^1)) or refrains from serving market k (configuration $(P_j^{1^{ne}}, P_k^1)$).

(ii) We establish the conditions NDD* and NDU* (formulated in Proposition 1) which ensure that each government has no incentive to deviate from t_j^* to these location changing tax rates, given t_k^*.

According to step a), we determine the equilibrium tax rates under the assumption that the plant location (P_j^1, P_k^1) is given, and then formulate conditions which guarantee that firms indeed choose (P_j^1, P_k^1) at these taxes. By substituting the equilibrium outputs (5a) - (5c) into the welfare function (20), differentiating it with respect to t_j and setting the derivative equal to zero, the tax reaction curve of government j for the given plant configuration (P_j^1, P_k^1) is obtained as

(21) $$t_j = \tfrac{1}{23}\left(4a - 16b + 12d - 2s + 7t_k\right).$$

The higher the output levels in the absence of a pollution tax (depending on market size a, marginal production costs b and transportation costs s), and the higher the marginal disutility of pollution d, the higher will be the welfare maximizing tax rate of a country, given the tax of the other country. The tax reaction curve is positively sloped, which means that taxes are strategic complements: if one government raises its tax rate by one unit, the optimal response of the other country is to raise its tax rate by $\frac{7}{23}$ units. By this response, production and employment as well as the tax revenues of the considered country increase, leading to a welfare gain that overcompensates the loss of consumer surplus. The intersection of the reaction curves of both countries determines the Nash-equilibrium in the environmental tax rates

(22) $$t_j^* = t_k^* = \tfrac{1}{8}\left(2a - 8b + 6d - s\right)$$

for the given market structure (P_j^1, P_k^1), characterized by one plant in each country and export production. The equilibrium tax levels are the lower, the higher the distortion on the labour market (the rigid wage rate affects b positively) and the lower the marginal disutility of pollution.

Next, we ensure that firms indeed serve the foreign market by exports, when faced with t_j^*, t_k^*: On the one hand, it must not be profitable for the firms to serve the foreign market by operating a subsidiary in the foreign country. On the other hand, it must not be profitable to refrain from serving the foreign market. These requirements give two conditions on the values of the exogenous parameters, denoted by NOS* and PEP*. Due to Lemma 1 they guarantee that exporting is a dominant strategy for each firm, given t_j^*, t_k^*, and thus induce location (P_j^1, P_k^1).

Each firm j has no incentive to operate a subsidiary in the foreign country, given the tax pair t_j^*, t_k^*, if it is more profitable to serve market k by exports, i. e. $\Delta\pi_j^{2\to 1}(t_j^*, t_k^*) < 0$[13]. By use of (17) and (22), this condition reads, in terms of exogenous parameters,

NOS* (<u>NO</u> foreign <u>S</u>ubsidiary at t_j^*, t_k^*): $g > \frac{s}{18}(6a - 6d - 7s)$.

Set-up costs g should be relatively high compared to the transportation costs s[14]. The latter, being the difference in average variable costs, are the reason that operating a subsidiary generates a higher producer surplus than exporting. This surplus is the greater, the larger the output produced for the foreign market. This in turn is the case, the greater the foreign market a and the smaller the marginal pollution damage d (and thereby the tax rates). Therefore, set-up costs must be sufficiently high that firms maintain their export strategy.

Each firm j has no incentive to refrain from serving the foreign market, if it is more profitable to export than not to export, i.e. $\Delta\pi_j^{1\to 1^{ne}}(t_j^*, t_k^*) > 0$. By use of (19) and (22), this condition reads

PEP* (<u>P</u>ositive <u>E</u>xport <u>P</u>rofits at t_j^*, t_k^*): $2a - 2d - 5s > 0$.

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13 By this condition, we introduce implicitly the convention that firm j builds up a subsidiary, whenever $\Delta\pi_j^{2\to 1} = 0$. This may be explained, e.g., by a greater (international) reputation for operating a subsidiary in the foreign country.

14 This is true only for small values of s. Larger values are excluded by condition PEP* (see next paragraph).

The size of the foreign market should not be too small in relation to the transportation costs s and to the marginal disutility of pollution d. The latter affects the equilibrium tax rates positively and thus lowers the firms’ export profits. We summarize step a):

If the parameters fulfill NOS and PEP*, the tax pair* t_j^*, t_k^* *support the plant configuration* (P_j^1, P_k^1) *as the Nash equilibrium in the second stage of the game and each government has no incentive to deviate to any other tax that maintains this location choice.*

Next, we continue with step b) and establish t_j^*, t_k^* as the subgame perfect strategies of the countries: It must not be attractive for a country to deviate to a tax rate that changes the export decision of a firm. By a sufficiently large tax cut, country j induces firm k to give up export production and firm j to maintain the export strategy. Depending on the size of the tax cut, it either achieves monopoly power in the domestic market (firm k refrains from supplying it) or gains a second plant (firm k opens a subsidiary). In both cases, it benefits from higher employment, but suffers from higher pollution levels. By an appropriate tax raise, country j looses the export production of firm j and thereby employment, but avoids pollution. Depending on the level of t_k^*, firm j either refrains from serving market k or establishes a subsidiary in country k. We proceed as follows: First, we specify the location changing tax levels by Lemma 2 and then we formulate the conditions under which governments do not deviate to any of these location changing tax levels by Proposition 1.

Lemma 2: *Given that parameters fulfill PEP* and NOS*,*

(i) there exist critical tax levels, denoted by $\bar{t}_j^{d2}, \underline{t}_j^{dne}$ *and* $\bar{t}_j^{dne}$*, so that the Nash-equilibrium in the second stage of the game is the location choice*

- (P_j^1, P_k^2) *for any tax pair* $(t_j \le \bar{t}_j^{d2},\ t_k^*)$*,*
- $(P_j^1, P_k^{1^{ne}})$ *for any tax pair* $(\underline{t}_j^{dne} < t_j \le \bar{t}_j^{dne},\ t_k^*)$*, if parameters fulfill condition (26).*

(ii) there exist critical tax levels, denoted by $\bar{t}_j^{u2}$ *and* $\bar{t}_j^{une}$*, so that the Nash-equilibrium in the second stage of the game is the location choice*

- (P_j^2, P_k^1) *for any tax pair* $(t_j \ge \bar{t}_j^{u2}, t_k^*)$*, if parameters fulfill condition (27),*
- $(P_j^{1^{ne}}, P_k^1)$ *for any tax pair* $(t_j \ge \bar{t}_j^{une}, t_k^*)$*, if parameters do not fulfill condition (27).*

Proof:

Assume that parameters fulfill NOS* and PEP*. Remember that, due to Lemma 1, the location decision of a firm is independent of the other firm's location decision.

(i) For firm j, the export strategy is strictly dominant at any tax pair $(t_j \le t_j^*,\ t_k^*)$ by the following reasoning: NOS* and PEP* guarantee that firm j chooses one plant with exporting at t_j^*, t_k^*. NOS* is defined by $\Delta\pi_j^{2\to1}(t_j^*, t_k^*) < 0$ and PEP* by $\Delta\pi_j^{1\to1^{ne}}(t_j^*, t_k^*) > 0$. Export production becomes more profitable for firm j in case of a tax cut in country j, as $\partial\Delta\pi_j^{2\to1}(t_j, t_k^*)/\partial t_j > 0$ and $\partial\Delta\pi_j^{1\to1^{ne}}(t_j, t_k^*)/\partial t_j < 0$.

For firm k, it is a dominant strategy to operate a subsidiary in country j, provided that $\Delta\pi_k^{2\to1}(t_j, t_k^*) \geq 0$ and $\Delta\pi_k^{2\to1^{ne}}(t_j) \geq 0$ [15]. $\Delta\pi_k^{2\to1}(t_j, t_k^*) \geq 0$ is equivalent to

(23) $$t_j \leq t_j^* + s - \frac{18g}{6a - 6d - 7s} =: \bar{t}_j^{d2},$$

with $\bar{t}_j^{d2} < t_j^*$, given NOS*. Due to $\Delta\pi_k^{2\to1^{ne}}(t_j) \geq 0$ for any $t_j \leq \bar{t}_j^{d2}$, given PEP* (see Appendix, Proof A), firm k decides for a foreign subsidiary not only against exporting but also against non-serving the foreign market at any tax pair ($t_j \leq \bar{t}_j^{d2}$, t_k^*).

On the other hand, it is a dominant strategy for firm k to refrain from serving market j, provided that $\Delta\pi_k^{1\to1^{ne}}(t_j, t_k^*) \leq 0$ [16] and $\Delta\pi_k^{2\to1^{ne}}(t_j) < 0$. The condition $\Delta\pi_k^{1\to1^{ne}}(t_j, t_k^*) \leq 0$ is equivalent to

(24) $$t_j \leq t_j^* - \tfrac{3}{8}(2a - 2d - 5s) =: \bar{t}_j^{dne},$$

with $\bar{t}_j^{dne} < t_j^*$, given PEP*. The condition $\Delta\pi_k^{2\to1^{ne}}(t_j) < 0$ is equivalent to

(25) $$t_j > a - b - 3\sqrt{g} =: \underline{t}_j^{dne}.$$

Provided that $\underline{t}_j^{dne} < \bar{t}_j^{dne}$, which is equivalent to

(26) $$g > \tfrac{1}{144}(6a - 6d - 7s)^2,$$

there exists tax pairs ($\underline{t}_j^{dne} < t_j \leq \bar{t}_j^{dne}$, t_k^*) that induce firm k to refrain from serving market j.

(ii) For firm k, export production is a strictly dominant strategy at any tax pair ($t_j \geq t_j^*$, t_k^*) by the following reasoning: NOS* and PEP* guarantee that firm k chooses one plant with exporting at t_j^*, t_k^*. NOS* is defined by $\Delta\pi_k^{2\to1}(t_j^*, t_k^*) < 0$ and PEP* by $\Delta\pi_k^{1\to1^{ne}}(t_j^*, t_k^*) > 0$. Export production becomes more profitable for firm k in case of a tax raise in foreign country j, as $\partial\Delta\pi_k^{2\to1}(t_j, t_k^*)\big/\partial t_j < 0$ and $\partial\Delta\pi_k^{1\to1^{ne}}(t_j, t_k^*)\big/\partial t_j > 0$.

For firm j, it is a dominant strategy to operate a subsidiary in the foreign country k, if $\Delta\pi_j^{2\to1}(t_j, t_k^*) \geq 0$ and $\Delta\pi_j^{2\to1^{ne}}(t_k^*) \geq 0$ holds. Note that the latter condition only depends on the tax rate of country k. Thus, country j cannot influence firm j's decision, whether to refrain from serving the foreign market or whether to serve it from a subsidiary. $\Delta\pi_j^{2\to1^{ne}}(t_k^*) \geq 0$ reads in terms of exogenous parameters

(27) $$g \leq \tfrac{1}{576}\left(6a - 6d + s\right)^2.$$

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15 Using the same notation for firm k and due to symmetry to (18) and (17), $\Delta\pi_k^{2\to1^{ne}}(t_j, t_k) = \frac{1}{9}(a - b - 2t_j)^2 - g$ and $\Delta\pi_k^{2\to1}(t_j, t_k) = \frac{1}{9}(a - b - 2t_j)^2 - g - \frac{1}{9}(a - b - 2s + t_j - 2t_k)^2$.

16 $\Delta\pi_k^{1\to1^{ne}}(t_j, t_k) \leq 0$, if $(a - b - 2s + t_j - 2t_k) \leq 0$, see also (19).

$\Delta\pi_j^{2\to1}(t_j, t_k^*) \geq 0$ is equivalent to

(28) $$t_j \geq t_j^* + \tfrac{1}{16}\left(3(2a-2d-5s) - \sqrt{(6a-6d+s)^2 - 576g}\right) =: \bar{t}_j^{u2}$$

with $\bar{t}_j^{u2} > t_j^*$ given NOS*[17]. $\bar{t}_j^{u}$ is defined in case that (27) holds.

If $\Delta\pi_j^{2\to1^{ne}}(t_k^*) < 0$ (i.e. parameters do not fulfill (27)), government j can induce firm j to refrain from serving market k by imposing a tax that fulfills the condition $\Delta\pi_j^{1\to1^{ne}}(t_j, t_k^*) \leq 0$, which is equivalent to

(29) $$t_j \geq t_j^* + \tfrac{3}{16}(2a-2d-5s) =: \bar{t}_j^{une}$$

with $\bar{t}_j^{une} > t_j^*$ given PEP*. QED.

Thus, government j can induce firm j to give up export production: If parameters fulfill (27), it decides for a foreign subsidiary, when confronted with a tax pair ($t_j \geq \bar{t}_j^{u2}$, t_k^*). This will be the case, if the set-up costs g are sufficiently small compared to the output level in the foreign market, which is the greater the larger the market size a and the lower t_k^* and thus the marginal environmental damage d. On the other hand, if parameters do not fulfill (27), firm j refrains from serving market k at any tax pair ($t_j \geq \bar{t}_j^{une}$, t_k^*). Next we formulate

Proposition 1: *Given t_k^*, government j has no incentive to deviate to any tax rate $t_j \neq t_j^*$, if parameters fulfill PEP*, NOS*, NDD* and NDU*.*

Proof:

We split the proof into three parts: In step (i) we establish condition NDD*, which guarantees that country j does not cut its tax rate to induce (P_j^1, P_k^2), given t_k^*. In step (ii) we investigate government j's incentive concerning a tax raise: We show that country j cannot induce the location choice (P_j^2, P_k^1), if parameters fulfill NOS*, PEP* and NDD*. We establish condition NDU* which ensures that country j has no incentive to induce $(P_j^{1^{ne}}, P_k^1)$. In step (iii) we show that NDU* is also a sufficient condition for country j for not having an incentive to induce $(P_j^1, P_k^{1^{ne}})$ by an appropriate tax cut.

Assume that parameters fulfill PEP* and NOS*.

(i) In order to determine whether it pays to change the firms' location choice to (P_j^1, P_k^2), government j compares welfare at t_j^* with the highest possible welfare at some tax rate $t_j \leq \bar{t}_j^{d2}$, given t_k^*. Let $\hat{t}_j^{d2}$ be the tax rate that meets the first order condition for maximization of $W_j[t_j, t_k^*, (P_j^1, P_k^2)]$ (denoting country j's welfare written as a function of t_j

[17] Solving $3(2a-2b-5s) > \sqrt{(6a-6d+s)^2 - 576g}$ for g yields exactly NOS*.

for (P_j^1, P_k^2)). $\hat{t}_j^{d2}$ is derived by substituting the outputs (7a), (7b) and (5c) and t_k^* into the welfare function (20), differentiating it with respect to t_j and setting the derivative equal to zero. It reads

(30) $$\hat{t}_j^{d2} = \bar{t}_j^{d2} + \frac{18g}{6a-6d-7s} + \frac{6a-6d-191s}{160}.$$

As $W_j[t_j, t_k^*, (P_j^1, P_k^2)]$ is strictly concave in t_j (see Appendix, Proof B), $\hat{t}_j^{d2}$ is the welfare maximum, if $\hat{t}_j^{d2} < \bar{t}_j^{d2}$. Otherwise, $\bar{t}_j^{d2}$ is the welfare maximizing tax rate inducing (P_j^1, P_k^2). Government j has no incentive to deviate from t_j^* to $\bar{t}_j^{d2}$, if

(31) $$W_j\left[t_j^*, t_k^*, (P_j^1, P_k^1)\right] > W_j\left[\bar{t}_j^{d2}, t_k^*, (P_j^1, P_k^2)\right]$$

holds. Substituting the corresponding tax rates and equilibrium outputs into the welfare function (20), (31) gives, in terms of the exogenous parameters,

NDD* (Non-Deviation Downwards from t_j^*):

$$1440g^2 + g(6a-6d-191s)(6a-6d-7s) - 9(a-d)^4 + \tfrac{515}{2}s^2(a-d)^2 - \tfrac{1631}{3}s^3(a-d) + \tfrac{43267}{144}s^4 > 0.$$

Moreover, it turns out (see Appendix, Proof C) that $\hat{t}_j^{d2} \geq \bar{t}_j^{d2}$ holds, if parameters fulfill NDD*. Hence, NDD* entails that $\bar{t}_j^{d2}$ maximizes $W_j[t_j, t_k^*, (P_j^1, P_k^2)]$, and, at the same time, that government j does not deviate to $\bar{t}_j^{d2}$. If parameters do not fulfill NDD* (but fulfill PEP* and NOS*), a government deviates to $\bar{t}_j^{d2}$ and clearly to $\hat{t}_j^{d2}$, if $\hat{t}_j^{d2} < \bar{t}_j^{d2}$.

(ii) If parameters fulfill NDD*, PEP* and NOS*, they do not fulfill (27) (see Appendix, Proof D). Hence, government j can only provide an incentive to the domestic firm to refrain from serving market k by a tax raise to $t_j \geq \bar{t}_j^{une}$, given t_k^*. For the determination of the welfare maximizing tax rate inducing $(P_j^{1^{ne}}, P_k^1)$, we calculate the tax rate that meets the first order condition for maximization of $W_j[t_j, t_k^*, (P_j^{1^{ne}}, P_k^1)]$. It reads

(32) $$\hat{t}_j^{une} = \bar{t}_j^{une} - \tfrac{3}{176}(26a - 26d - 81s)$$ [18].

As $W_j[t_j, t_k^*, (P_j^{1^{ne}}, P_k^1)]$ is strictly concave in t_j (see Appendix, Proof E), $\bar{t}_j^{une}$ is the welfare maximizing tax rate inducing $(P_j^{1^{ne}}, P_k^1)$, provided that $\hat{t}_j^{une} < \bar{t}_j^{une}$. In this case, government j never raises its tax above t_j^*, as

(33) $$W_j[t_j^*, t_k^*, (P_j^1, P_k^1)] > W_j[\bar{t}_j^{une}, t_k^*, (P_j^{1^{ne}}, P_k^1)]$$

holds for all parameter values[19]. Given that $\hat{t}_j^{une} \geq \bar{t}_j^{une}$, $\hat{t}_j^{une}$ is the welfare maximum for $(P_j^{1^{ne}}, P_k^1)$. In this case, government j has no incentive to deviate to $\hat{t}_j^{une}$, if

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18 $\hat{t}_j^{une}$ is derived by substituting (5a), (5b), (11a) and t_k^* into (20), differentiating this term with respect to t_j and setting the derivative equal to zero.

19 (33) reads in terms of the exogenous parameters $\frac{23}{512}(2a - 2d - 5s)^2 > 0$.

(34) $W_j[t_j^*, t_k^*, (P_j^1, P_k^1)] > W_j[\hat{t}_j^{une}, t_k^*, (P_j^{1^{ne}}, P_k^1)]$

holds. Substituting the corresponding tax rates and equilibrium outputs into the welfare function, (34) reads, in terms of the exogenous parameters,

NDU* (Non-Deviation Upwards from t_j^*): $84(a-d)^2 - s(212a - 212d + 59s) > 0$.

Condition NDU* ensures that government j has no incentive to raise its tax above t_j^* by the following reasoning: Parameters that do not fulfill NDU*, but PEP* imply $\hat{t}_j^{une} \geq \bar{t}_j^{une}$ (see Appendix, Proof F). Thus, at these parameters, government j would deviate to $\hat{t}_j^{une}$, while it has no incentive to raise its tax above t_j^*, if parameters fulfill NDU*, because NDU* (in addition to PEP*) implies either $\hat{t}_j^{une} \geq \bar{t}_j^{une}$ or $\hat{t}_j^{une} < \bar{t}_j^{une}$.

(iii) Assume that parameters fulfill (26). Only in this case, government j can induce firm k to refrain from serving market j. In order to determine whether to do so, government j compares welfare at t_j^* with the highest possible welfare at some tax rate $\underline{t}_j^{dne} < t_j \leq \bar{t}_j^{dne}$, given t_k^*. The tax rate that meets the first order condition for maximization of $W_j[t_j, t_k^*, (P_j^1, P_k^{1ne})]$ reads

(35) $\hat{t}_j^{dne} = \bar{t}_j^{dne} + \frac{1}{100}(82a - 82d - 209s)$ [20].

We show that $W_j[t_j, t_k^*, (P_j^1, P_k^{1ne})]$ is strictly concave in t_j (see Appendix, Proof G) and that NDU* and PEP* imply $\hat{t}_j^{dne} > \bar{t}_j^{dne}$ (see Appendix, Proof H). In this case, $\bar{t}_j^{dne}$ is the welfare maximizing tax rate inducing (P_j^1, P_k^{1ne}) [21] and we can restrict to show that

(36) $W_j[t_j^*, t_k^*, (P_j^1, P_k^1)] > W_j[\bar{t}_j^{dne}, t_k^*, (P_j^1, P_k^{1^{ne}})]$

holds for all parameter values[22]. Thus we conclude that government j has no incentive to induce (P_j^1, P_k^{1ne}) by a tax cut, given parameters fulfill NDU*. QED.

Figure 1 illustrates Proposition 1 in a diagram with marginal pollution damage d on the horizontal axis and set-up costs g on the vertical axis for given market size and transportation costs. Figure 1b replicates Figure 1a at higher marginal transportation costs, while 1c replicates 1a at a higher market size.

Figure 1

20 $\hat{t}_j^{dne}$ is derived by substituting (13a), (13b), (5c) and t_k^* into (20), differentiating this term with respect to t_j and setting the derivative equal to zero.

21 On the other hand, $\hat{t}_j^{dne}$ would be the welfare maximum, if $\underline{t}_j^{dne} < \hat{t}_j^{dne} \leq \bar{t}_j^{dne}$, while $\underline{t}_j^{dne} + \chi$, χ arbitrarily small, would be the welfare maximum, if $\hat{t}_j^{dne} \leq \underline{t}_j^{dne}$.

22 (36) reads in terms of the exogenous parameters $\frac{23}{128}(2a - 2d - 5s)^2 > 0$.

The area above the line labeled by NOS* (indicated by the arrow) and to the left of the line PEP* indicates those parameter constellations that induce firms to choose plant location (P_j^1, P_k^1), if faced with the tax rates t_j^*, t_k^*. The parameter combinations that induce each government j to impose the equilibrium tax t_j^*, given t_k^*, are indicated by the shaded area above the line labeled NDD* and below NDU*.

First, we study the conditions NDD* and NDU* in Figure 1a: It is rationale for a government not to compete for a second plant by a tax cut, if set up costs are high, because high set up costs imply that the tax has to be cut strongly to compensate firm k for these set up costs[23]. This and a high marginal disutility of pollution lead to welfare losses due to a change in tax revenues and in environmental damage[24], which are not compensated by gains in employment and in consumer surplus. On the other hand, each country j has no incentive to raise the tax level above t_j^* to induce the domestic firm to give up export production, if the marginal disutility of pollution is not too high for given transportation costs and given size of the foreign market. In this case, the benefits of higher environmental quality and the change in tax revenues does not outweigh the negative effect on employment and consumer surplus.

The analysis of comparative statics show the following (see Figure 1b and 1c): The incentive of government j to undercut each other to gain a second plant is greater at higher transportation costs or higher market size (NDD* shifts to the right)[25]. On the other hand, the incentive to induce $(P_j^{1^{ne}}, P_k^1)$ by a tax raise increases at higher transportation costs (NDU* shifts to the left), but reduces at a greater market size (NDU* shifts to the right)[26]. Consequently, higher transportation costs cause a reduction of the parameter region supporting $[t_j^*, t_k^*, (P_j^1, P_k^1)]$, while a greater market size results in a shift of this area to the right.

Finally note the position of NDD* and NDU* in relation to NOS* and PEP*. Governments have no incentive to deviate, only if firms are relatively immobile (high g and low s), marginal disutility of pollution is relatively high and markets are relatively small compared to the parameter values that induce firms to choose (P_j^1, P_k^1) at t_j^*, t_k^*. Thus if parameters fall short of a critical value (i.e. conditions NOS* and PEP* hold, but not NDD*), then it would pay for each government to undercut. This will be the parameter region of our interest in the next section.

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23 as $\Delta t_j := t_j^* - \bar{t}_j^{d2} = \frac{18g}{6a-6d-7s} - s$, see (23).

24 Note that tax revenues ΔT may decrease or increase depending on the parameter values. All we know is that $\Delta T - \Delta D < 0$, ΔD =: additional environmental damage.

25 As higher values of these two parameters reduce the extent of the tax cut necessary to induce (P_j^2, P_k^1), a deviation to $\bar{t}_j^{d2}$ is profitable also at higher levels of marginal disutility of pollution.

26 Because higher transportation costs or a lower market size increase the extent of the optimal tax raise $\hat{t}_j^{une} - t_j^* =$ $= \frac{3}{88}(-2a + 2d + 13s)$, see (32), marginal disutility of pollution must be lower in order that governments does not outbid each other.

3.2 The establishment of subsidiaries as a result of interjurisdictional competition

The case of mobile firms and low marginal environmental damage

Given that parameters fulfill PEP* and NOS*, but do not meet NDD*, governments are able to induce the location choice (P_j^1, P_k^1) by imposing t_j^*, t_k^*. But each has an incentive to cut its tax below t_j^* in order to obtain a second plant in its country. In this case interjurisdictional competition may set off a race to the bottom, resulting in lower tax rates and two plants in each country. We will show that such a subgame perfect equilibrium, denoted by $[t_j^{**}, t_k^{**}, (P_j^2, P_k^2)]$, exists, if firms are rather mobile and marginal disutility of pollution is relatively low. We compute the range of parameter values that support $[t_j^{**}, t_k^{**}, (P_j^2, P_k^2)]$ as a subgame perfect equilibrium by the following steps:

a) We determine the tax pair t_j^{**}, t_k^{**} which fulfills the following two requirements:
   (i) They induce each firm to decide for two plants,
   (ii) Each government j has no incentive to deviate from t_j^{**} to any other tax rate that maintains firms' location choice (P_j^2, P_k^2), given t_k^{**},

   provided that parameters fulfill NOS* and PEP**. We will show that NOS* and PEP* imply PEP**. Thus , t_j^{**}, t_k^{**} meet the requirements (i) and (ii) at parameter values that give rise to location (P_j^1, P_k^1) at t_j^*, t_k^*[27].

b) As each government j can induce a location change by a unilateral variation of the tax level, we formulate conditions which guarantee that it has no incentive to deviate from t_j^{**} to any of these location changing taxes, given t_k^{**}. Like in section 3.1 this will be done in two parts:
   (i) We show (in Lemma 3) that given that parameters fulfill PEP**,
   - any unilateral tax raise above t_j^{**} induces firm j to decide for exporting against operating a subsidiary in country k (configuration (P_j^1, P_k^2)).
   - any unilateral tax cut below t_j^{**} induces firm k to choose exporting (configuration (P_j^2, P_k^1)).

   (ii) We establish the conditions NDD** and NDU** (formulated in Proposition 2) which ensure that each government j has no incentive to deviate from t_j^{**}, given t_k^{**}.

Assume that parameters fulfill NOS* and PEP* guaranteeing that firms choose location (P_j^1, P_k^1) at t_j^*, t_k^*. We will show that the tax pair determined by the conditions $\Delta\pi_j^{2\to1}(t_j, t_k) = 0$ and $\Delta\pi_k^{2\to1}(t_j, t_k) = 0$ meets the requirements (i) and (ii) defined in step a). Calculating the point of intersection gives us

(37) $$t_j^{**} = t_k^{**} = a - b - s - \frac{9g}{4s}$$

[27] Note that this is exactly the situation we are interested in: Firms would choose (P_j^1, P_k^1), if they were confronted with t_j^*, t_k^*, but governments impose taxes to induce them to choose (P_j^2, P_k^2).

with $t_j^{**} < t_j^*$, given NOS*, as $t_j^{**} = t_j^* + \frac{1}{8}[(6a - 6d - 7s) - \frac{18g}{s}]$. First, note that t_j^{**}, t_k^{**} are the highest tax rates compatible with $\Delta\pi_j^{2\to1}(t_j, t_k) \geq 0$ due to the fact that $\Delta\pi_j^{2\to1}$ decreases in t, t := t_j = t_k, as $\partial\Delta\pi_j / \partial t = -\frac{4}{9}s$. Further, firms indeed choose (P_j^2, P_k^2) at t_j^{**}, t_k^{**}, regardless whether they have positive export profits or not. This is straightforward by solving $\Delta\pi_k^{2\to1^{ne}}(t_j) \geq 0$ and $\Delta\pi_j^{2\to1^{ne}}(t_k) \geq 0$ for the tax of the corresponding country, which gives

(38a) $t_j \leq a - b - 3\sqrt{g} =: \bar{\bar{t}}_j$ (38b) $t_k \leq \bar{\bar{t}}_k$, $\bar{\bar{t}}_k = \bar{\bar{t}}_j$.

with $t_j^{**} \leq \bar{\bar{t}}_j$ [28].

Next, we have to investigate the incentive of the governments concerning a deviation to a tax that maintains the location choice (P_j^2, P_k^2). Country j's welfare $W_j[t_j, (P_j^2, P_k^2)]$, written as a function of t_j for (P_j^2, P_k^2), is independent of the other country's tax t_k and strictly concave in t_j[29]. Thus, out of all tax pairs that induce both firms to decide for a foreign subsidiary, t_j^{**}, t_k^{**} has to maximize $W_j[t_j, (P_j^2, P_k^2)]$ resp. $W_k[t_k, (P_j^2, P_k^2)]$, given NOS* and PEP*. The tax rate that meets the first order condition for maximization of $W_j[t_j, (P_j^2, P_k^2)]$, denoted by $\tilde{t}_j$, is always higher than t_j^*, as $\tilde{t}_j = t_j^* + \frac{s}{8}$. Consequently, given NOS*, $\Delta\pi_j^{2\to1}(\tilde{t}_j, \tilde{t}_k) < 0$ and t_j^{**}, t_k^{**} are the welfare maximizing tax rates for both countries, provided that one qualification is made: Export profits must be nonnegative at t_j^{**}, t_k^{**}. Otherwise each government j would improve its welfare by imposing a tax t_j, $t_j^{**} < t_j \leq \bar{\bar{t}}_j$ [30], that preserves (P_j^2, P_k^2) [31]. We exclude this possibility by the condition $\Delta\pi_j^{1\to1^{ne}}(t_j^{**}, t_k^{**}) \geq 0$. It reads, in terms of the exogenous parameters,

PEP** (<u>P</u>ositive <u>E</u>xport <u>P</u>rofits at t_j^{**}, t_k^{**}) $\frac{9g}{4s} - s \geq 0$.

Finally we show (see Appendix, Proof I) that NOS* and PEP* imply PEP**. Thus given that firms choose (P_j^1, P_k^1) at t_j^*, t_k^*, each country j cannot improve by deviating from t_j^{**} to a tax that maintains (P_j^2, P_k^2). We conclude:

The tax pair t_j^{**}, t_k^{**} support the plant configuration (P_j^2, P_k^2) as a Nash equilibrium in the second stage of the game. Given t_k^{**}, each government j has no incentive to deviate to a tax level that maintains this location choice (P_j^2, P_k^2), if parameters fulfill NOS and PEP**.*

Now we turn to step b) and establish t_j^{**}, t_k^{**} as the subgame perfect strategies of the countries. For this, we proceed as follows: We specify the location changing tax levels in

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28 Doing some transformation, the difference $\bar{\bar{t}}_j - t_j^{**}$ is equivalent to $\frac{1}{s}(s - \frac{3}{2}\sqrt{g})^2$.

29 Substituting (10a) and (10b) into (13) gives $W_j[t_j, (P_j^2, P_k^2)] = \frac{2}{9}(a - b - t_j)^2 + \frac{2}{3}(b - d + t_j)(a - b - t_j)$. The second derivative is $\partial^2 W_j[t_j, (P_j^2, P_k^2)] / \partial t_j^2 = -\frac{8}{9}$.

30 Government j would maximize $W_j[t_j, (P_j^2, P_k^2)]$ by setting the tax level either to $\tilde{t}_j$, if $\tilde{t}_j \leq \bar{\bar{t}}_j$ or to $\bar{\bar{t}}_j$, if $\bar{\bar{t}}_j < \tilde{t}_j$.

31 In this case, it would be more profitable for the firms to operate a subsidiary in the foreign country than to refrain from serving the foreign market, which in turn would yield higher profits than exporting.

Lemma 3. Then we formulate the conditions under which governments have no incentive to deviate to any of these location changing tax levels by Proposition 2.

Lemma 3: *Given that parameters fulfill PEP**, the Nash-equilibrium of the second stage is*

- *the firms' location choice* (P_j^1, P_k^2) *for any tax pair* ($t_j < t_j^{**}, t_k^{**}$).
- *the firms' location choice* (P_j^2, P_k^1) *for any tax pair* ($t_j > t_j^{**}, t_k^{**}$).

Proof:

It is organized as follows: We determine the location decisions of firm j first and next those of firm k due to a variation in t_j, given t_k^{**}. Remember that a location decision of a firm is independent of the other firm's location due to Lemma 1. Assume that parameters fulfill PEP**.

(i) The first derivatives of (17) and (19) with respect to t_j have a determinate sign: $\partial\Delta\pi_j^{2\to1}(t_j, t_k^{**})/\partial t_j > 0$ and $\partial\Delta\pi_j^{1\to1^{ne}}(t_j, t_k^{**})/\partial t_j < 0$. It follows: For any tax $t_j < t_j^{**}$, $\Delta\pi_j^{2\to1}(t_j, t_k^{**}) < 0$ and $\Delta\pi_j^{1\to1^{ne}}(t_j, t_k^{**}) > 0$ [32], given PEP**, and firm j decides for exporting at any tax pair ($t_j < t_j^{**}, t_k^{**}$). For any tax $t_j > t_j^{**}$, $\Delta\pi_j^{2\to1}(t_j, t_k^{**}) > 0$. By this and by $\Delta\pi_j^{2\to1^{ne}}(t_k^{**}) \geq 0$, firm j decides for a subsidiary in country k at any tax pair ($t_j > t_j^{**}, t_k^{**}$).

(ii) We have $\partial\Delta\pi_k^{2\to1}(t_j, t_k^{**})/\partial t_j < 0$, $\partial\Delta\pi_k^{1\to1^{ne}}(t_j, t_k^{**})/\partial t_j > 0$ and $\partial\Delta\pi_k^{2\to1^{ne}}(t_j)/\partial t_j < 0$. Thus, for any tax $t_j < t_j^{**}$, $\Delta\pi_k^{2\to1}(t_j, t_k^{**}) > 0$ and $\Delta\pi_k^{2\to1^{ne}}(t_j) > 0$ [33], and firm k decides for operating a subsidiary in country j at any tax pair ($t_j < t_j^{**}, t_k^{**}$). On the other hand, for any tax $t_j > t_j^{**}$, $\Delta\pi_k^{2\to1}(t_j, t_k^{**}) < 0$ and $\Delta\pi_k^{1\to1^{ne}}(t_j, t_k^{**}) > 0$ [34], given PEP**. Thus, firm k decides for exporting at any tax pair ($t_j > t_j^{**}, t_k^{**}$). QED.

So by any tax cut, each country gains the export production of the domestic firm and thereby employment, but suffers from higher pollution. By any tax raise, it forgoes the establishment of a subsidiary within its boundaries and thus pollution and employment. Next, we study the welfare implications of these location changing taxes and formulate

Proposition 2: *Given* t_k^{**}*, government j has no incentive to deviate to any tax rate* t_j „ t_j^{**}*, if parameters fulfill NOS*, PEP**, NDD** and NDU**.*

Proof:

We split the proof into two parts: First, we establish condition NDD**, which guarantees that country j does not cut its tax rate below t_j^{**}, given t_k^{**}. Next, we formulate condition NDU**, which guarantees that country j does not raise its tax rate above t_j^{**}, given t_k^{**}.

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32 Remember that $\Delta\pi_j^{2\to1}(t_j^{**}, t_k^{**}) = 0$ and that PEP** is defined by $\Delta\pi_j^{1\to1^{ne}}(t_j^{**}, t_k^{**}) \geq 0$.

33 Remember also that $\Delta\pi_k^{2\to1}(t_j^{**}, t_k^{**}) = 0$ and $\Delta\pi_k^{2\to1^{ne}}(t_j^{**}) \geq 0$.

34 Remember that $\Delta\pi_k^{1\to1^{ne}}(t_j^{**}, t_k^{**}) \geq 0$, ensured by PEP**.

Assume that parameters fulfill NOS* and PEP**.

(i) In order to decide whether to change the firms' location choice to (P_j^1, P_k^2), government j compares welfare at t_j^{**} with the highest possible welfare at some tax rate $t_j < t_j^{**}$, given t_k^{**}. Let $\hat{t}_j^D$ be the tax rate that meets the first order condition for maximization of $W_j[t_j, t_k^{**}, (P_j^1, P_k^2)]$. It reads, in terms of the exogenous parameters and t_j^{**},

(39) $\hat{t}_j^D = t_j^{**} - \frac{1}{20}(12a - 12d - 11s - \frac{153g}{4s})$ [35]

As $W_j[t_j, t_k^{**}, (P_j^1, P_k^2)]$ is strictly concave in t_j (see Appendix, Proof B), $\hat{t}_j^D$ is the welfare maximum, if $\hat{t}_j^D < t_j^{**}$. Otherwise, $\bar{t}_j^D := t_j^{**} - \gamma$, γ arbitrarily small, is the welfare maximizing tax rate inducing (P_j^1, P_k^2). Government j has no incentive to deviate from t_j^{**} to $\bar{t}_j^D$, if

(40) $W_j\left[t_j^{**}, t_k^{**}, (P_j^2, P_k^2)\right] > W_j\left[\bar{t}_j^D, t_k^{**}, (P_j^1, P_k^2)\right]$

holds. In order to express (40) in terms of the parameter values, we define the condition $\Delta W_j \geq 0$, $\Delta W_j := W_j[t_j^{**}, t_k^{**}, (P_j^2, P_k^2)] - W_j[t_j^{**}, t_k^{**}, (P_j^1, P_k^2)]$. It is straightforward that this condition implies (40), provided that $t_j^{**} \leq \hat{t}_j^D$. ΔW_j is equal to $-(b - d + t_j^{**}) x_{jk}(t_j^{**}, t_k^{**}, (P_j^1, P_k^2))$. Given PEP**, $x_{jk}(t_j^{**}, t_k^{**}, (P_j^1, P_k^2)) \geq 0$ and, thus, $\Delta W_j \geq 0$ reduces to $(-b + d - t_j^{**}) \geq 0$. Substituting t_j^{**} into this term, yields

NDD** (<u>N</u>on-<u>D</u>eviation from t_j^{**}): $\frac{9g}{4s} - a + d + s \geq 0$.

It turns out (see Appendix, Proof J) that $\hat{t}_j^D \geq t_j^{**}$, if parameters fulfill NDD** and PEP**. Hence, NDD** entails that $\bar{t}_j^D$ maximizes $W_j[t_j, t_k^{**}, (P_j^1, P_k^2)]$, and, at the same time, that government j does not deviate to $\bar{t}_j^D$. If parameters do not fulfill NDD** (but fulfill PEP**), it deviates to $\bar{t}_j^D$ and clearly to $\hat{t}_j^D$, if $\hat{t}_j^D < t_j^{**}$.

(ii) Government j decides whether to induce (P_j^2, P_k^1) by comparing welfare at t_j^{**} with the highest welfare at some tax rate $t_j > t_j^{**}$, given t_k^{**}. The tax rate that meets the first order condition for maximization of $W_j[t_j, t_k^{**}, (P_j^2, P_k^1)]$, denoted by $\hat{t}_j^U$, reads

(41) $\hat{t}_j^U = t_j^{**} - \frac{1}{11}(6a - 6d - 11s - \frac{63g}{4s})$ [36].

As $W_j[t_j, t_k^{**}, (P_j^2, P_k^1)]$ is strictly concave in t_j (see Appendix, Proof K), $\hat{t}_j^U$ is the local welfare maximum, if $\hat{t}_j^U > t_j^{**}$. It is shown in the Appendix (Proof L) that $\hat{t}_j^U > t_j^{**}$ holds, provided that parameters fulfill NDD**. Thus, whenever government j does not want to undercut, $\hat{t}_j^U$ maximizes $W_j[t_j, t_k^{**}, (P_j^2, P_k^1)]$. By this, we can restrict to formulate the

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[35] $\hat{t}_j^D$ is derived by substituting (7a), (7b), (5c) and t_k^{**} into (20), differentiating it with respect to t_j and setting the derivative equal to zero.

[36] $\hat{t}_j^U$ is derived by substituting (5a) and (5b) and t_k^{**} into (20), differentiating it with respect to t_j and setting the derivative equal to zero.

condition for non-deviation to $\hat{t}_j^U$. Government j has no incentive to deviate from t_j^{**} to $\hat{t}_j^U$, if

(42) $W_j\left[t_j^{**}, t_k^{**}, (P_j^2, P_k^2)\right] > W_j\left[\hat{t}_j^U, t_k^{**}, (P_j^2, P_k^1)\right]$.

(42) reads in terms of the exogenous parameters,

NDU** (Non-Deviation Upwards from t_j^{**}):

$$-9315g^2 + 72gs(75a - 75d - 88s) + 64s^2\left(33s(a-d) - 9(a-d)^2 - 22s^2\right) > 0 .$$

It turns out (Appendix, Proof M) that $\hat{t}_j^U > t_j^{**}$ holds, if parameters fulfill the conditions NDU** and NDD**. Hence, these two conditions entail that government j does not deviate to $\hat{t}_j^U$ nor to $\bar{t}_j^D$ and, at the same time, that $\hat{t}_j^U$ maximizes $W_j[t_j, t_k^{**}, (P_j^2, P_k^1)]$ as well as $\bar{t}_j^D$ maximizes $W_j[t_j, t_k^{**}, (P_j^1, P_k^2)]$. QED.

This completes the proof that parameters fulfilling NOS*, PEP**, NDD** and NDU** support $[t_j^{**}, t_k^{**}, (P_j^2, P_k^2)]$ as a subgame perfect equilibrium. Figure 2 sums up this result in a diagram with marginal disutility of pollution on the horizontal axis and set-up costs on the vertical axis for the same values of a and s as in Figure 1.

Figure 2

In order that the equilibrium $[t_j^{**}, t_k^{**}, (P_j^2, P_k^2)]$ is realized, firms must be more mobile (lower set up costs and higher marginal transportation costs), marginal disutility of pollution must be lower and markets must be greater compared to the parameter values that support $[t_j^*, t_k^*, (P_j^1, P_k^1)]$ as a subgame perfect equilibrium. It pays for each government to undercut $t_j^* = t_k^*$ to get a second plant in its country and each is content with a pair of tax rates, by which each of them has a second plant, but lost export production of the home firm.

Each government has no incentive to deviate from t_j^{**}, t_k^{**} to any other tax level that maintains firms' location choice (P_j^2, P_k^2) at parameters constellations above the lines labeled by PEP** and NOS*[37]. The parameter combinations at which governments have no incentive to deviate to any location changing tax rate are indicated by the shaded area above the line labeled NDD** and below NDU**.

If parameters fulfill NDD**, country j has no incentive to cut its tax below t_j^{**}, by which it would gain the export production of the domestic firm. It does not reduce the tax level by an arbitrarily small amount γ, which is the optimal location changing tax cut, if the marginal disutility of

[37] Each government would benefit from a tax raise that maintains (P_j^2, P_k^2), if parameters do not fulfill PEP** or NOS* (see step a).

pollution is high in relation to the equilibrium tax t_j^{**}. In this case, the additional pollution damage would overcompensate the positive employment effect and the additional tax revenues[38]. The level of t_j^{**}[39] (t_j^{**} - γ inducing (P_j^1, P_k^2) resp.) is higher, the more mobile firms are (the greater s and the lower g) and the greater market size a is. In this case, the gain in tax revenues is higher and, consequently, the constant marginal disutility of pollution must be higher, in order that governments have no incentive to undercut each other.

If parameters fulfill NDU**, each government j has no incentive to raise the tax above t_j^{**}, by which it would forgo a second plant in its country. Set up costs affect the extent of optimal tax raise $\Delta t_j = \hat{t}_j^U - t_j^{**}$ positively. Thus at low set up costs and a low marginal disutility of pollution the change in tax revenues[40] and the gain in environmental quality due to this tax raise does not outweigh the negative effect on employment and on consumer surplus. The incentive of the governments to outbid each other is smaller at higher transportation costs or higher market size. As higher values of the transportation costs or of the market size reduce the extent of the tax raise[41], deviation is not attractive also at higher levels of marginal disutility of pollution.

Most remarkable, the parameter region supporting $[t_j^{**}, t_k^{**}, (P_j^2, P_k^2)]$ as a subgame perfect equilibrium expands by higher transportation costs (Figure 2b). They raise the governments' willingness not to deviate upwards by more than they decrease their willingness not to deviate downwards, i.e. NDU** shifts relatively more upwards than NDD**. So the probability for interjurisdictional competition resulting in two plants in each country is much greater at higher marginal transportation costs. On the other hand, a greater foreign market size (Figure 2c) raises the governments' incentive not to outbid each other by the same amount as it reduces the governments incentive not to undercut each other (NDU** and NDD** shifts to the right by the same amount.).

4. Welfare analysis

This section deals with the question whether interjurisdictional competition resulting in additional plants is destructive in the presence of involuntary unemployment. If this is the case, the welfare of each country would be improved by a coordination of the national tax policies. We assess the welfare effects in two steps: First, we derive the joint welfare maximizing tax

[38] Note that the change in consumer surplus is arbitrarily small, as the tax cut is arbitrarily small.

[39] t_j^{**} increases, if s increases, given PEP**.

[40] Note that tax revenues may increase or decrease depending on the parameter values.

[41] The tax difference $\hat{t}_j^u - t_j^{**}$ decreases, if s increases, given PEP**, see also (41).

levels which induce firms to choose (P_j^1, P_k^1) and (P_j^2, P_k^2) [42] by maximizing the weighted sum of welfare functions of the countries $W^{agg}(t_j, t_k) = \alpha_j W_j + \alpha_k W_k$ for arbitrary weights α_j, α_k. We find the following results formulated in Lemma 4 and 5: Whenever parameters support either the non cooperative outcome $[t_j^*, t_k^*, (P_j^1, P_k^1)]$ or $[t_j^{**}, t_k^{**}, (P_j^2, P_k^2)]$, both countries cannot improve by a coordinated tax policy that preserves the corresponding firms' location choice. Second, we analyze whether a tax coordination that changes locations leads to a pareto improvement. For this, we compare aggregate welfare at the two tax pairs. This allows us to establish conditions for a pareto improving environmental tax design in Proposition 3.

Lemma 4: *The joint welfare maximizing tax rates that induce firms' location choices* (P_j^1, P_k^1) *coincide with the non cooperative taxes* t_j^*, t_k^**, provided that parameters fulfill PEP* and NOS*.*

Proof:

Aggregate welfare $W^{agg}[t_j, t_k, (P_j^1, P_k^1)]$, written as a function of t_j and t_k for the plant configuration (P_j^1, P_k^1), reads

(43)
$$\begin{aligned} W^{agg}[t_j, t_k, (P_j^1, P_k^1)] &= \alpha_j W_j[t_j, t_k, (P_j^1, P_k^1)] + \alpha_k W_k[t_j, t_k, (P_j^1, P_k^1)] \\ &= \alpha_j \left[\tfrac{1}{2}\left(x_{jj}(t_j, t_k) + x_{kj}(t_j, t_k)\right)^2 + \left(b + t_j - d\right)\left(x_{jj}(t_j, t_k) + x_{jk}(t_j, t_k)\right) \right] + \\ &\quad \alpha_k \left[\tfrac{1}{2}\left(x_{kk}(t_j, t_k) + x_{jk}(t_j, t_k)\right)^2 + \left(b + t_k - d\right)\left(x_{kk}(t_j, t_k) + x_{kj}(t_j, t_k)\right) \right] \end{aligned}$$

Differentiating the Cournot quantities (5a) - (5d) with respect to the taxes of both countries, $\frac{\partial x_{jj}}{\partial t_j} = \frac{\partial x_{jk}}{\partial t_j} = -\frac{2}{3}$, $\frac{\partial x_{kk}}{\partial t_j} = \frac{\partial x_{kj}}{\partial t_j} = +\frac{1}{3}$, we derive the first order conditions for the maximization of $W^{agg}[t_j, t_k, (P_j^1, P_k^1)]$,

(44a)
$$\begin{aligned} \frac{\partial W^{agg}[t_j, t_k, (P_j^1, P_k^1)]}{\partial t_j} &= \alpha_j \left[-\tfrac{1}{3}\left(x_{jj}(t_j, t_k) + x_{kj}(t_j, t_k)\right) + x_{jj}(t_j, t_k) + x_{jk}(t_j, t_k) - \tfrac{4}{3}\left(b + t_j - d\right) \right] + \\ &\quad + \alpha_k \left[-\tfrac{1}{3}\left(x_{kk}(t_j, t_k) + x_{jk}(t_j, t_k)\right) + \tfrac{2}{3}\left(b + t_k - d\right) \right] \end{aligned}$$

(44b)
$$\begin{aligned} \frac{\partial W^{agg}[t_j, t_k, (P_j^1, P_k^1)]}{\partial t_k} &= \alpha_j \left[-\tfrac{1}{3}\left(x_{jj}(t_j, t_k) + x_{kj}(t_j, t_k)\right) + \tfrac{2}{3}\left(b + t_j - d\right) \right] \\ &\quad + \alpha_k \left[-\tfrac{1}{3}\left(x_{kk}(t_j, t_k) + x_{jk}(t_j, t_k)\right) + x_{kk}(t_j, t_k) + x_{kj}(t_j, t_k) - \tfrac{4}{3}\left(b + t_k - d\right) \right] \end{aligned}$$

We analyze (44a) and (44b) at the non cooperative taxes t_j^*, t_k^*. Some manipulations[43] will yield the result that

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[42] We do not consider side payments to compensate a potential looser. So we do not study asymmetric plant configurations, because in case of identical countries and firms one country is always worse off.

[43] For calculation, see Appendix, Proof N.

(45a) $\left.\frac{\partial W^{agg}}{\partial t_j}\right|_{\substack{t_j=t_j^* \\ t_k=t_k^*}} = \frac{1}{2}\alpha_k\left[x_{kj}(t_j^*,t_k^*)-x_{jk}(t_j^*,t_k^*)\right]$ (45b) $\left.\frac{\partial W^{agg}}{\partial t_k}\right|_{\substack{t_j=t_j^* \\ t_k=t_k^*}} = \frac{1}{2}\alpha_j\left[x_{jk}(t_j^*,t_k^*)-x_{kj}(t_j^*,t_k^*)\right]$.

Setting (45a) and (45b) equal to zero gives the first order conditions for (P_j^1,P_k^1), which coincide with the countries' best responses t_j^*,t_k^* in the non cooperative game if export quantities are the same in both countries. This is the case, provided that countries and firms are identical[44] - as we assume in our model - and provided that firms' location choices are (P_j^1,P_k^1), i.e. parameters fulfill PEP* and NOS*. QED.

A reason for this result is that our measure of welfare does not include the firms' profits as in many other studies. Thus there is no rent-seeking argument as illustrated, for example, in the models of strategic trade policy (Brandner, Spencer, 1986) or in the case of pollution taxes by Hung (1994), which allows for welfare improving cooperation also in the case of identical countries and firms. Next we determine the joint welfare maximizing tax rates generating (P_j^2,P_k^2) and formulate

Lemma 5: *The joint welfare maximizing tax rates that induce firms' location choice* (P_j^2,P_k^2) *coincide with the non cooperative tax levels* t_j^{**},t_k^{**}*, provided that parameters fulfill NOS* and PEP**.*

Proof:

We know from section 3.2 that the non cooperative tax pair t_j^{**},t_k^{**} induce firms' location choice (P_j^2,P_k^2) with t_j^{**} maximizing $W_j[t_j,(P_j^2,P_k^2)]$ and t_k^{**} maximizing $W_k[t_k,(P_j^2,P_k^2)]$[45], provided that parameters fulfill NOS* and PEP**. Thus, for these parameter constellations, the equilibrium tax rates t_j^{**},t_k^{**} maximize also aggregate welfare

(46) $$W^{agg}[t_j,t_k,(P_j^2,P_k^2)] = \alpha_j W_j[t_j,(P_j^2,P_k^2)] + \alpha_k W_k[t_k,(P_j^2,P_k^2)],$$

due to $\partial W^{agg}[t_j,t_k,(P_j^2,P_k^2)]/\partial t_j = \alpha_j\,\partial W_j[t_j,(P_j^2,P_k^2)]/\partial t_j$ and $\partial W^{agg}[t_j,t_k,(P_j^2,P_k^2)]/\partial t_k = \alpha_k\,\partial W_k[t_k,(P_j^2,P_k^2)]/\partial t_k$. QED.

We conclude Lemma 4 and 5: Whenever parameters support either the non cooperative outcome $[t_j^*,t_k^*,(P_j^1,P_k^1)]$ or $[t_j^{**},t_k^{**},(P_j^2,P_k^2)]$, both countries cannot improve by a coordinated tax policy that preserves the corresponding firms' location choices. Finally we analyze under

[44] Note that in the case of heterogeneous countries and firms, aggregate welfare can be increased by a cooperative solution. For example, a greater marginal environmental damage in country j implies - all else equal - that the non cooperative tax rate t_j^* of country j is higher than the non cooperative tax rate t_k^* of country k and thus firm k has higher exports than firm j. Then (45a) is positive and (45b) is negative in the non cooperative outcome, and there is room for a pareto improvement by a tax raise in country j and a tax cut in country k.

[45] Remember that each country's welfare at (P_j^2,P_k^2) depends only on the domestic tax level.

which conditions a tax coordination that allows for location changes leads to a pareto improvement and formulate the results in

Proposition 3: *Given parameter values that support the non cooperative equilibrium* $[t_j^{**}, t_k^{**}, (P_j^2, P_k^2)]$ *and firms' location choice* (P_j^1, P_k^1) *at* t_j^*, t_k^**, a cooperation of both countries to* t_j^*, t_k^* *improves welfare of both countries, only in case that these parameters fulfill also PIC*.*

Proof:

Assume that parameters support the non cooperative equilibrium $[t_j^{**}, t_k^{**}, (P_j^2, P_k^2)]$. In this case (i.e. parameters fulfill NOS*, PEP**, NDD** and NDU**), an international tax coordination to t_j^*, t_k^* will induce (P_j^1, P_k^1), if parameters fulfill PEP* in addition[46]. And it will result in an efficiency gain, if

(47) $$W^{agg}\left[t_j^*, t_k^*, (P_j^1, P_k^1)\right] > W^{agg}\left[t_j^{**}, t_k^{**}, (P_j^2, P_k^2)\right].$$

Substituting the corresponding equilibrium taxes and outputs into aggregate welfare (43) and (46), (47) reads, in terms of the exogenous parameters,

PIC* (<u>P</u>areto <u>I</u>mprovement by <u>C</u>ooperation to t_j^*, t_k^*):

$$\tfrac{1}{16}(2a - 2d - s)^2 + \tfrac{1}{36s^2}(9g + 4s^2)(9g - 2s(3s - 3d - 2s)) > 0$$ QED.

We conclude: Given that parameters support the equilibrium $[t_j^{**}, t_k^{**}, (P_j^2, P_k^2)]$ and fulfill PEP*, both countries benefit from inducing (P_j^1, P_k^1) by a cooperation to t_j^*, t_k^*, if parameters fulfill PIC*, while countries cannot improve, if parameters do not fulfill PIC*[47]. Compared to the previous literature, the welfare implications of interjurisdictional competition differ substantially in the presence of involuntary unemployment. These studies showed that in the presence of a perfect labour market, mobile capital and strategic policy makers who do not have access to the requisite policy instruments, interjurisdictional competition is destructive. Our model implies that this inefficient outcome does not necessarily arise depending on the parameter constellations: At the non cooperative equilibrium $[t_j^{**}, t_k^{**}, (P_j^2, P_k^2)]$ each country attracted a subsidiary of the foreign firm, but lost the export production of the home firm and has a higher production level due to the lower tax rates and the removal of the transportation costs compared to a tax coordination to t_j^*, t_k^*. If at t_j^*, t_k^* the welfare loss due to a decrease in employment and consumer surplus is higher than the avoided environmental damage and the change in tax revenues, countries cannot improve by a coordinated policy that avoids a

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46 Remember that firms choose (P_j^1, P_k^1) at t_j^*, t_k^*, provided that parameters fulfill PEP* and NOS*.

47 If parameters support the equilibrium $[t_j^*, t_k^*, (P_j^1, P_k^1)]$ and fulfill PIC*, countries cannot improve from inducing (P_j^1, P_k^1) by a cooperation to t_j^{**}, t_k^{**}, while they can improve, if parameters do not fulfill PIC*, but support $[t_j^*, t_k^*, (P_j^1, P_k^1)]$. This is the case only at some rare parameter constellations, i.e. at the highest possible mobility of firms (see Figure 3), still supporting $[t_j^*, t_k^*, (P_j^1, P_k^1)]$.

competition for plants. This result points to the large weight of employment in the welfare function.

An illustration of Proposition 3 is given in Figure 3.

Figure 3

The parameter region that supports the non cooperative equilibrium $[t_j^{**}, t_k^{**}, (P_j^2, P_k^2)]$ is divided into two areas in Figure 3a: Given the market size and the marginal transportation costs, there is room for a pareto improvement, provided that the set-up costs g are high relatively to the marginal environmental damage d, while countries cannot improve by moving to t_j^*, t_k^*, if the relation g to d is relatively low. The region, at which countries cannot improve, expands at higher marginal transportation costs. This is illustrated in figure 3b, where countries cannot improve at all combinations of g and d that support the non cooperative equilibrium $[t_j^{**}, t_k^{**}, (P_j^2, P_k^2)]$. In contrast, at a greater market, the parameter region, where an international commitment to t_j^*, t_k^* leads to a pareto improvement, has expanded (see figure 3c). So given the parameter region that supports equilibrium $[t_j^{**}, t_k^{**}, (P_j^2, P_k^2)]$ countries can only improve by a tax coordination to t_j^*, t_k^*, if firms are rather mobile (low g and high s), marginal environmental damage is low and markets are large. At these parameter combinations the tax difference $t_j^* - t_j^{**}$ is quite small. This together with the direct impact of the marginal transportation costs on the export quantity leads only to a slight production decrease and consequently to such a moderate negative effect on employment and on consumer surplus that it is outweighed by the welfare gain due to higher environmental quality and change in tax revenues.

5. Concluding remarks

The presented model analyzes environmental policy in the presence of strategic policy makers, endogenous location choice and imperfect labour and product markets. It argues that governments, who compete for plants via environmental taxes, pursue multiple goals. This leads to a second best solution where the tax levels are set by trading off welfare gains from employment, consumer surplus and tax revenues against welfare losses arising from pollution.

We have modeled an interjurisdictional competition between two countries in a three stage game where governments set simultaneously an environmental tax in the first stage and two firms decide in stage two either to serve the foreign market by exports or by operating a subsidiary abroad. In stage three firms are assumed to play Cournot. Depending on the exogenous parameters two symmetric equilibria are identified and regions of parameters are given which support the respective non cooperative equilibrium. The first equilibrium, where the competition among the countries does not result in additional plants, is realized, if the marginal disutility of pollution is quite high and firms are rather immobile. Due to the poor mobility, governments would have to reduce taxes significantly to obtain a second plant in their country, and in the presence of high marginal disutility of pollution it does not pay to do so. In the second equilibrium each government sets the environmental tax to a level that induces the foreign firm to establish a plant in its country. It prevails, if the marginal disutility of pollution is lower and firms are more mobile compared to the first equilibrium. This interjurisdictional competition might help to rationalize the widely observed fact that governments do not introduce tax levels which prevent pollution efficiently, but impose taxes which guarantee that domestic firms do not loose market shares and induces foreign firms to invest in their country.

In contrast to the results of previous studies which neglected labour market effects, a coordination of environmental taxation which avoids this race to the bottom will not necessarily lead to a pareto improvement. This result seems relevant for applied environmental policy, as a "conventional wisdom" seems to have emerged concerning the need for a centralization of environmental policies in the European Union (Oates, 1997). The argument for this community-wide harmonization is that interjurisdictional competition leads to inefficient outcomes, if governments have some scope for strategic behaviour. This is a common result of many studies on this topic, but all of them assume a perfect labour market. But as most member countries are faced with high persistent involuntary unemployment, European policy makers should be aware that a centralized environmental policy that avoids the competition among the member states for plants and market shares via environmental taxes, does not automatically result in an efficiency gain. Instead instruments that fight unemployment should be given priority. Although this policy recommendation can be deducted from our results, the robustness of our results should be checked first. A more sophisticated model to explain involuntary unemployment and/or to analyze the interaction of several instruments in order to reduce both employment and environmental pollution simultaneously using a general equilibrium setting provides a demanding task for future research and would help to make reliable statements. Nevertheless the results of our model give an important insight why countries do not adopt stricter anti-pollution policies, as it is often observed in reality, and that a centralized environmental policy may not result in a pareto improvement in the presence of involuntary unemployment.

Appendix

Proof A: $\Delta\pi_k^{2\to1^{ne}}(t_j) \geq 0$ for any $t_j \leq \bar{t}_j^{d2}$, if parameters fulfill PEP*.

The proof is organized as follows: Solving $\Delta\pi_k^{2\to1^{ne}}(t_j) \geq 0$ for t_j gives

(A1) $\quad t_j \leq a - b - 3\sqrt{g}$.

Thus, we prove that PEP* implies that

(A2) $\quad \bar{t}_j^{d2} \leq a - b - 3\sqrt{g}$

with $\bar{t}_j^{d2} = \frac{1}{8}(2a - 8b + 6d + 7s - \frac{144g}{6a-6d-7s})$ (see (23)).

This is immediate by calculating the difference $(a - b - 3\sqrt{g}) - \bar{t}_j^{d2}$ and doing some easy transformation. The difference $(a - b - 3\sqrt{g}) - \frac{1}{8}(2a - 8b + 6d + 7s - \frac{144g}{6a-6d-7s})$, is equal to

(A3) $\quad \dfrac{(6a - 6d - 7s - 12\sqrt{g})^2}{8(6a - 6d - 7s)}$.

This term is positive, if parameters fulfill PEP*.

Proof B: $W_j[t_j, t_k, (P_j^1, P_k^2)]$, $t_k = t_k^*$, t_k^{**} is strictly concave in t_j.

Substituting the equilibrium outputs (7a), (7b) and (5c) into (20) gives

(B1) $\quad W_j[t_j, t_k, (P_j^1, P_k^2)] = \frac{2}{9}(a - b - t_j)^2 + \frac{1}{3}(b - d + t_j)(3a - 3b - 2s - 4t_j + t_k)$.

The second derivative of (B1) is $\dfrac{\partial^2 W_j[t_j, t_k, (P_j^1, P_k^2)]}{\partial t_j^2} = -\dfrac{20}{9}$.

Proof C: NDD*, PEP* and NOS* imply that $\hat{t}_j^d \geq \bar{t}_j^d$.

NDD* is of second order in g, solving NDD* for g yields two separate inequalities, denoted by NDD*1 and NDD*2[i] (NDD*1 refers to the negative value of the square root, NDD*2 to the positive value):

(NDD*1) $\quad g < \frac{1}{2880}\left[-(6a - 6d - 191s)(6a - 6d - 7s) - \sqrt{3}\sqrt{(6a - 6d - 7s)^2\left(492(a-d)^2 + 356s(a-d) + 387s^2\right)}\right]$

(NDD*2) $\quad g > \frac{1}{2880}\left[-(6a - 6d - 191s)(6a - 6d - 7s) + \sqrt{3}\sqrt{(6a - 6d - 7s)^2\left(492(a-d)^2 + 356s(a-d) + 387s^2\right)}\right]$

Note that the term under the square root is positive, if PEP* (which implies a > d) holds. The right hand side of NDD*1 is denoted by T1, that of NDD*2 by T2.

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[i] To be precise: Parameters fulfilling either NDD*1 or NDD*2 fulfill NDD*.

We proceed as follows: In a first step (i) we show that NOS* (i.e. $g > \frac{s}{18}(6a-6d-7s)$) and PEP* (i.e. $2a-2d-5s>0$) imply that NDD*1 does not hold (i.e. g > T1). In a second step (ii) we show that NDD*2 (i.e. g > T2) implies that $\hat{t}_j^d \geq \bar{t}_j^d$.

(i) We show that $\frac{s}{18}(6a-6d-7s)$ > T1, given PEP*. The difference [$\frac{s}{18}(6a-6d-7s)-$T1] is written explicitly as

(C1) $\frac{1}{2880}\left[(6a-6d-31s)(6a-6d-7s)+\sqrt{3}\sqrt{(6a-6d-7s)^2\left(492(a-d)^2+356s(a-d)+387s^2\right)}\right]$.

That (C1) is positive, follows from the following considerations: If PEP* holds, we have

(C2) $40(6a-6d+s)(6a-6d+5s)(6a-6d-7s)^2 > 0$,

as PEP* implies a > d. As $40(6a-6d+s)(6a-6d+5s) = 3\left(492(a-d)^2+356s(a-d)+387s^2\right)-$ $-(6a-6d-31s)^2$, (C2) is equivalent to

(C3) $3\left(492(a-d)^2+356s(a-d)+387s^2\right)(6a-6d-7s)^2 > (6a-6d-31s)^2(6a-6d-7s)^2$.

Taking the square root on both sides of (C3) gives

(C4) $\sqrt{3}\sqrt{(6a-6d-7s)^2\left(492(a-d)^2+356s(a-d)+387s^2\right)} > \pm(6a-6d-31s)(6a-6d-7s)$,

which completes the proof that (C1) is positive.

(ii) As $\hat{t}_j^d - \bar{t}_j^d = \frac{18g}{6a-6d-7s}+\frac{6a-6d-191s}{160}$ (see equation (30)), $\hat{t}_j^d \geq \bar{t}_j^d$ is equivalent to

(C5) $g \geq -\frac{1}{2880}(6a-6d-191s)(6a-6d-7s)$.

That T2 > $-\frac{1}{2880}(6a-6d-191s)(6a-6d-7s)$ is immediate, hence g > T2 implies $\hat{t}_j^d \geq \bar{t}_j^d$.

Proof D: PEP*, NOS* and NDD* imply that (27) does not hold.

We know from Proof C that NDD* can be written in two separate inequalities NDD*1 and NDD*2 and that PEP* and NOS* imply that NDD*1 does not hold. It remains to show that PEP* (i.e. $2a-2d-5s>0$) and NDD*2 (i.e. g > T2) imply that (27) does not hold (i.e. $g > \frac{1}{576}(6a-6d+s)^2$).

We show that T2 > $\frac{1}{576}(6a-6d+s)^2$, given PEP*. The difference T2 $-\ \frac{1}{576}(6a-6d+s)^2$ is written explicitly as

(D1) $\frac{1}{2880}\left[-2(18a-18d-61s)(6a-6d-11s)+\sqrt{3}\sqrt{(6a-6d-7s)^2\left(492(a-d)^2+356s(a-d)+387s^2\right)}\right]$.

That (D1) is positive, follows from the following considerations: If PEP* holds, we have

(D2) $5[(6a-6d)^4+10044s(2a-2d-4s)^3+3238s^2(6a-6d-10s)^2+9s^3(2312a-2312d-3311s)]>0$,

as PEP* implies that $2a-2d-4s>0$ and $2312a-2312d-3311s>0$. (D2) is equivalent to

(D3) $3(6a-6d-7s)^2\left(492(a-d)^2+356s(a-d)+387s^2\right)>4(6a-6d-11s)^2(18a-18d-61s)^2$,

as $5[(6a-6d)^4+10044s(2a-2d-4s)^3+3238s^2(6a-6d-10s)^2+9s^3(2312a-2312d-3311s)]=$
$=3(6a-6d-7s)^2\left(492(a-d)^2+356s(a-d)+387s^2\right)-4(6a-6d-11s)^2(18a-18d-61s)^2$. Taking the square roots on both sides of (D3) gives

(D4) $\sqrt{3}\sqrt{(6a-6d-7s)^2\left(492(a-d)^2+356s(a-d)+387s^2\right)}>\pm 2(6a-6d-11s)(18a-18d-61s)$,

which completes the proof that (D1) is positive. Hence, g > T2 imply that (27) does not hold.

Proof E: $W_j[t_j, t_k^*, (P_j^{1ne}, P_k^1)]$ is strictly concave in t_j.

Substituting the equilibrium outputs (5a), (5b) and (11a) into (20) gives

(E1) $W_j[t_j, t_k^*, (P_j^{1ne}, P_k^1)]=\frac{1}{18}(2a-2b-s-t_j-t_k^*)^2+\frac{1}{3}(b-d+t_j)(a-b+s-2t_j+t_k^*)$.

The second derivative of (E1) is $\dfrac{\partial^2 W_j[t_j, t_k^*, (P_j^{1ne}, P_k^1)]}{\partial t_j^2}=-\dfrac{11}{9}$.

Proof F: Parameters that fulfill PEP*, but not NDU*, imply $\hat{t}_j^{une}\geq \bar{t}_j^{une}$.

NDU* is of second order in d, solving NDU* for d yields two separate inequalities, denoted by NDU*1 and NDU*2[ii] (NDU*1 refers to the positive value of the square root, NDU*2 to the negative value):

(NDU*1) $d>a-\dfrac{53s}{42}+\dfrac{2s}{21}\sqrt{253}$ (NDU*2) $d<a-\dfrac{53s}{42}-\dfrac{2s}{21}\sqrt{253}$.

The right hand side of NDU*1 is denoted by V1, that of NDU*2 by V2.

We proceed as follows: In a first step (i) we show that PEP* (i.e. $d<a-\frac{5}{2}s$) implies that NDU*1 does not hold (i.e. d < V1). In step (ii) we show that $\hat{t}_j^{une}\geq \bar{t}_j^{une}$, if NDU*2 does not hold (i.e. d > V2).

(i) We show that V1> $a-\frac{5}{2}s$. The difference [V1 $-(a-\frac{5}{2}s)$] is equal to

(F1) $\frac{2}{21}s(\sqrt{253}-13)$.

This term is positive, as $\sqrt{253}>13$. Hence, $d<a-\frac{5}{2}s$ implies d < V1.

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ii To be precise: Parameters fulfilling either NDU*1 or NDU*2 fulfill NDU*.

(ii) As $\hat{t}_j^{une} - \bar{t}_j^{une} = -\frac{3}{176}(26a - 26d - 81s)$, see (35), $\hat{t}_j^{une} \geq \bar{t}_j^{une}$ is equivalent to

(F2) $\quad d \geq a - \frac{81}{26}s$.

We show that V2 > $a - \frac{81}{26}s$. The difference [V2 – $(a - \frac{81}{26}s)$] is equal to

(F3) $\quad \frac{2}{273}s(253 - 13\sqrt{253})$,

which is positive, as $253 > 13\sqrt{253}$. Hence, d > V2 implies $d \geq a - \frac{81}{26}s$.

Proof G: $W_j[t_j, t_k^*, (P_j^1, P_k^{1^{ne}})]$ is strictly concave in t_j.

Substituting the equilibrium outputs (13a), (13b) and (5c) into (20) gives

(G1) $\quad W_j[t_j, t_k, (P_j^1, P_k^2)] = \frac{1}{8}(a - b - t_j)^2 + (b - d + t_j)[\frac{1}{2}(a - b - t_j) + \frac{1}{3}(a - b - 2s - 2t_j + t_k^*)$.

The second derivative of (G1) is $\dfrac{\partial^2 W_j[t_j, t_k^*, (P_j^1, P_k^{1^{ne}})]}{\partial t_j^2} = -\dfrac{25}{12}$.

Proof H: NDU* and PEP* imply $\hat{t}_j^{dne} > \bar{t}_j^{dne}$.

NDU* can be written in two separate inequalities NDU*1 and NDU*2 (see Proof F) and it is shown in Proof F that PEP* implies that NDU*1 does not hold. It remains to show that NDU*2 (i.e. d < V2) implies that $\hat{t}_j^{dne} > \bar{t}_j^{dne}$.

As $\hat{t}_j^{dne} - \bar{t}_j^{dne} = \frac{1}{100}(82a - 82d - 209s)$ (see (32)), $\hat{t}_j^{dne} > \bar{t}_j^{dne}$ is equivalent to

(H1) $\quad d < a - \frac{209}{82}s$.

We show that $a - \frac{209}{82}s$ > V2. The difference [$(a - \frac{81}{26}s)$ – V2] is equal to

(H2) $\quad \frac{2}{861}s(41\sqrt{253} - 554)$.

This term is positive, as $41\sqrt{253} > 554$. Hence, d < V2 implies $d < a - \frac{209}{82}s$.

Proof I: NOS (i.e. $g > \frac{s}{18}(6a - 6d - 7s)$) and PEP* (i.e. $2a - 2d - 5s > 0$) imply PEP** (i.e. $g \geq \frac{4}{9}s^2$)

We show that $\frac{s}{18}(6a - 6d - 7s) > \frac{4}{9}s^2$, if parameters fulfill PEP*: This is immediate by calculating the difference $\frac{s}{18}(6a - 6d - 7s) - \frac{4}{9}s^2$, which is equal to

(I1) $\frac{s}{6}(2a - 2d - 5s)$.

Hence, $g > \frac{s}{18}(6a - 6d - 7s)$ implies $g \geq \frac{4}{9}s^2$, given PEP*.

Proof J: PEP** (i.e. $9g - 4s^2 \geq 0$) and NDD** (i.e. $a \leq d + s + \frac{9g}{4s}$) imply that $\hat{t}_j^D \geq t_j^{**}$.

As $\hat{t}_j^D - t_j^{**} = -\frac{1}{20}(12a - 12d - 11s - \frac{153g}{4s})$, (see (39)), $\hat{t}_j^D \geq t_j^{**}$ is equivalent to

(J1) $a \leq d + \frac{11s}{12} + \frac{51g}{16s}$.

We show that $(d + \frac{11s}{12} + \frac{51g}{16s}) > (d + s + \frac{9g}{4s})$, given PEP**: The difference $(d + \frac{11s}{12} + \frac{51g}{16s}) - (d + s - \frac{9g}{4s})$ is equal to

(J2) $\frac{s}{48}(45g - 4s^2)$.

If parameters fulfill PEP**, (J2) is positive, and hence $a \leq d + s + \frac{9g}{4s}$ implies $a \leq d + \frac{11s}{12} + \frac{51g}{16s}$.

Proof K: $W_j[t_j, t_k^{**}, (P_j^2, P_k^1)]$ is strictly concave in t_j.

Substituting the equilibrium outputs for (P_j^2, P_k^1) , (7a) and (7d) into (20) gives

(K1) $W_j[\ \ _j\ t_k^{**}, (P_j^2\ \ \ _k^1)] = \frac{1}{18}(2a - 2b - \ \ - t_j - t_k^{**}\ \ ^2 + \frac{1}{3}(\ \ - d + t_j)(\ \ - b + s - \ \ \ _j + t_k^{**}$.

The second derivative of (K1) is $\frac{\partial^2 W_j[t_j, t_k^{**}, (P_j^2, P_k^1)]}{\partial t_j^{\ 2}} = -\frac{11}{9}$.

Proof L: NDD** (i.e. $a \leq d + s + \frac{9g}{4s}$) implies $\hat{t}_j^U > t_j^{**}$.

As $\hat{t}_j^U - t_j^{**} = -\frac{1}{11}(6a - 6d - 11s - \frac{63g}{4s})$, (see (41)), $\hat{t}_j^U > t_j^{**}$ is equivalent to

(L1) $a < d + \frac{11s}{6} + \frac{21g}{8s}$.

We show that $(d + \frac{11s}{6} + \frac{21g}{8s}) > (d + s + \frac{9g}{4s})$. This is immediate by calculating the difference $(d + \frac{11s}{6} + \frac{21g}{8s}) - (d + s + \frac{9g}{4s})$, which is equal to

(L2) $(\frac{3g}{8s} + \frac{5s}{6})$.

Hence, $a \leq d + s + \frac{9g}{4s}$ implies $a < d + \frac{11s}{6} + \frac{21g}{8s}$.

Proof M: NDU** and NDD** implies $\hat{t}_j^U > t_j^{**}$.

NDU** is of second order in a, solving NDU** for a yields two separate inequalities, denoted by NDU**1 and NDU**2 (NDU**1 refers to the positive value of the square root, NDU**2 to the negative value):

(NDU**1) $$a < d + \frac{11s}{6} + \frac{75g}{16s} + \frac{1}{16s}\sqrt{\frac{11}{3}(405g^2 + 432gs^2 + 64s^4)}$$

(NDU**2) $$a > d + \frac{11s}{6} + \frac{75g}{16s} - \frac{1}{16s}\sqrt{\frac{11}{3}(405g^2 + 432gs^2 + 64s^4)}$$

We denote the right hand side of NDU**1 by U1, that of NDU**2 by U2. Note that NDU** is equivalent to U2 < a < U1.

We will show that $\hat{t}_j^U > t_j^{**}$ holds, if parameters fulfill NDD** and NDU**. The proof is organized as follows: In a first step (i) we show that NDD** (i.e. $a \le d + s + \frac{9g}{4s}$) implies NDU**1 (i.e. a < U1), thereby making use of the result of Proof L that NDD** implies $\hat{t}_j^U > t_j^{**}$. In a second step (ii) we show that there exists a range of parameters that fulfill both NDD2** (i.e. a > U2) and $\hat{t}_j^U > t_j^{**}$ (i.e. $a < d + \frac{11s}{6} + \frac{21g}{8s}$).

(i) We show that $U1 > d + s + \frac{9g}{4s}$. This is immediate by calculating the difference $[\,U1 - (d + s + \frac{9g}{4s})\,]$, which is equal to

(M1) $$\frac{5s}{6} + \frac{33g}{16s} + \frac{1}{16s}\sqrt{\frac{11}{3}(405g^2 + 432gs^2 + 64s^4)}\ .$$

(ii) We show that $d + \frac{11s}{6} + \frac{21g}{8s} > U2$. The difference $[\,d + \frac{11s}{6} + \frac{21g}{8s} - U2\,]$ is written explicitly as

(M1) $$\frac{1}{16s}\left(-33g + \sqrt{\frac{11}{3}(405g^2 + 432gs^2 + 64s^4)}\right).$$

That (M1) is positive, follows from the following considerations: We have

(M2) $$\frac{11}{3}(108g^2 + 432gs^2 + 64s^4) > 0\ .$$

As $\frac{11}{3}(108g^2 + 432gs^2 + 64s^4) = -(33g)^2 + \frac{11}{3}(405g^2 + 432gs^2 + 64s^4)$, (M2) is equivalent to

(M3) $$(33g)^2 < \frac{11}{3}(405g^2 + 432gs^2 + 64s^4)\ .$$

Taking the square root on both sides of (M3) gives

(M4) $$\pm 33g < \sqrt{\frac{11}{3}(405g^2 + 432gs^2 + 64s^4)}\ ,$$

which completes the proof that (M1) is positive.

Proof N: $\left.\frac{\partial W^{agg}[t_j,t_k,(P_j^1,P_k^1)]}{\partial t_j}\right|_{\substack{t_j=t_j^*\\ t_k=t_k^*}} = \frac{1}{2}\alpha_k\left[x_{kj}(t_j^*,t_k^*) - x_{jk}(t_j^*,t_k^*)\right]$ (see (45a)).

Making use of the fact that

(N1) $$\left.\frac{\partial W_j[t_j,t_k,(P_j^1,P_k^1)]}{\partial t_j}\right|_{t_j=t_j^*} = 0\,,$$

(44a) reduces to

(N2) $$\left.\frac{\partial W^{agg}[t_j,t_k,(P_j^1,P_k^1)]}{\partial t_j}\right|_{t_j=t_j^*} = \alpha_k\left[-\frac{1}{3}\left(x_{kk}(t_j^*,t_k^*) + x_{jk}(t_j^*,t_k^*)\right) + \frac{2}{3}\left(b + t_k^* - d\right)\right].$$

Making use of the fact that

(N3) $$\left.\frac{\partial W_k[t_j,t_k,(P_j^1,P_k^1)]}{\partial t_k}\right|_{t_k=t_k^*} = \alpha_k\left[-\frac{1}{3}\left(x_{kk}(\cdot) + x_{jk}(\cdot)\right) + x_{kk}(\cdot) + x_{kj}(\cdot) - \frac{4}{3}\left(b + t_k^* - d\right)\right] = 0$$

and of some easy transformations of the form

(N4) $$\alpha_k\left[-\frac{1}{3}\left(x_{kk}(t_j^*,t_k^*) + x_{jk}(t_j^*,t_k^*)\right) + \frac{2}{3}\left(b + t_k^* - d\right)\right] = -\frac{1}{2}\alpha_k\Big[\left(x_{kk}(\cdot) + x_{jk}(\cdot)\right) - \frac{1}{3}\left(x_{kk}(\cdot) + x_{jk}(\cdot)\right) - \frac{4}{3}\left(b + t_k^* - d\right) + x_{ke}(\cdot) - x_{ke}(\cdot)\Big],$$

(N2) reduces to (45a). In the same manner (45b) is calculated.

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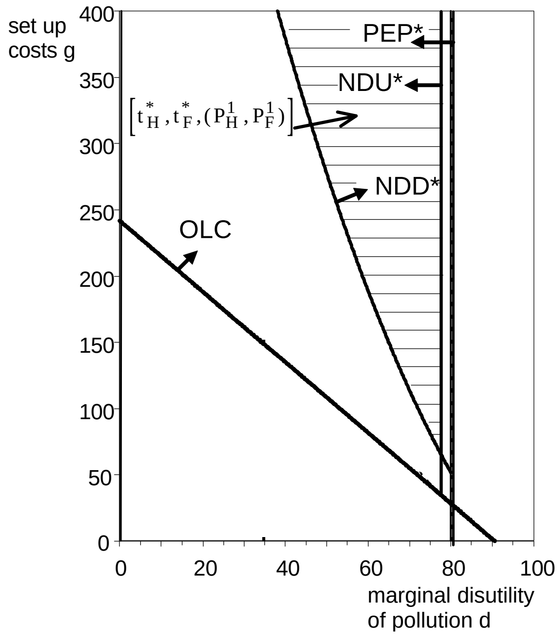
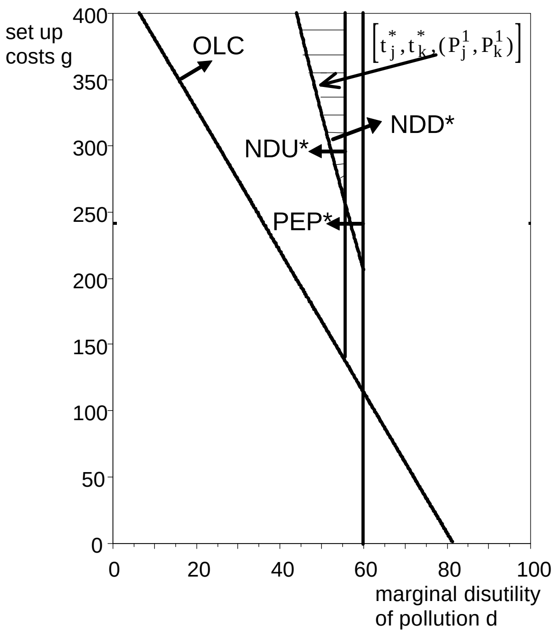
Figure 1

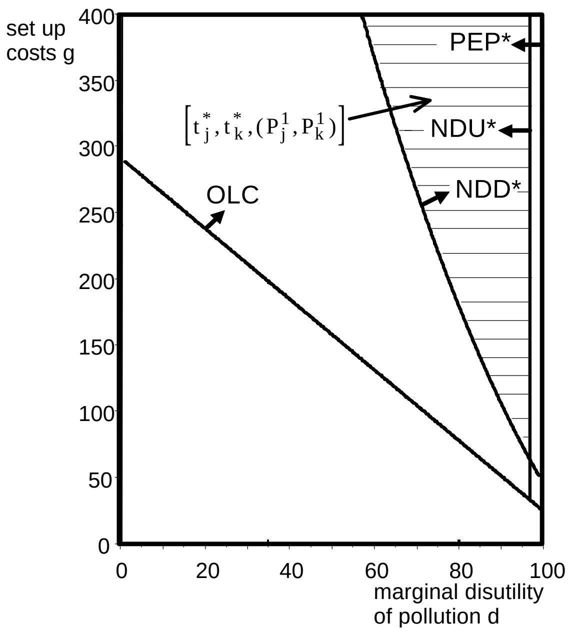
Interjurisdictional competition resulting in no additional plants
Equilibrium [$t_j^*, t_k^*, (P_j^1, P_k^1)$]



a) Parameterization: market size a = 100
transportation costs s = 8



b) Parameterization: a = 100
s = 16



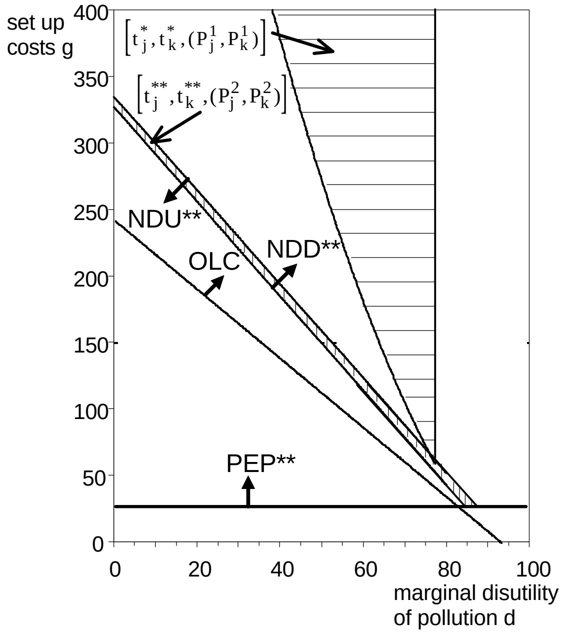
c) Parameterization: a = 120
s = 8

The arrows indicate the corresponding parameter regions.

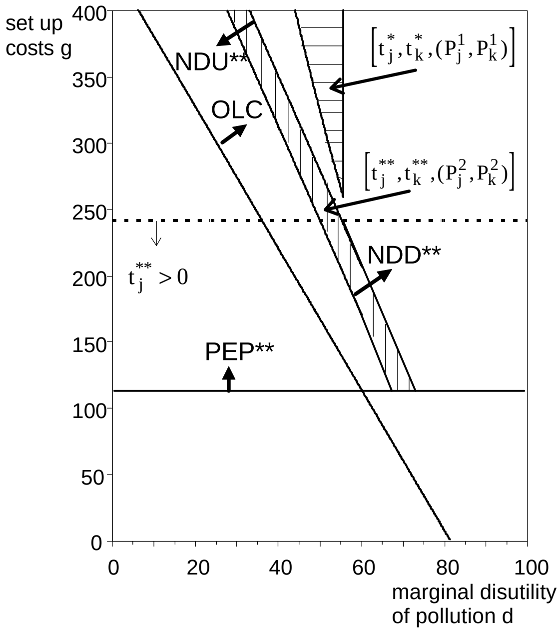
Figure 2

Interjurisdictional competition resulting in additional plants

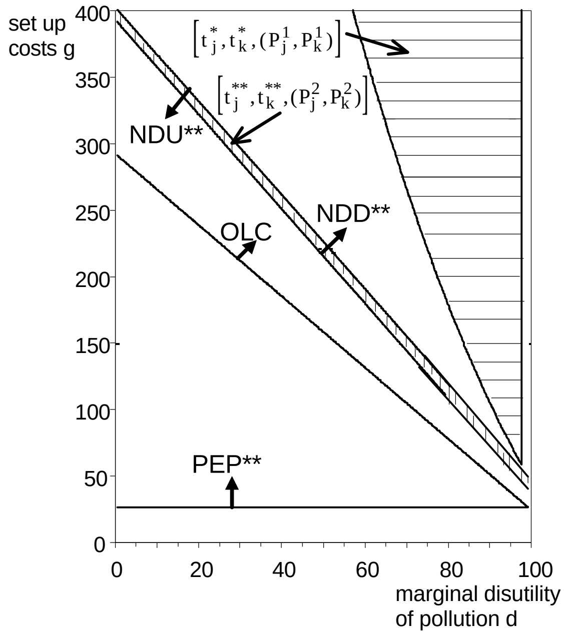
Equilibrium $[\,t_j^{**}, t_k^{**}, (P_j^2, P_k^2)\,]$



a) Parameterization: market size a = 100
transportation costs s = 8



b) Parameterization: a = 100
s = 16

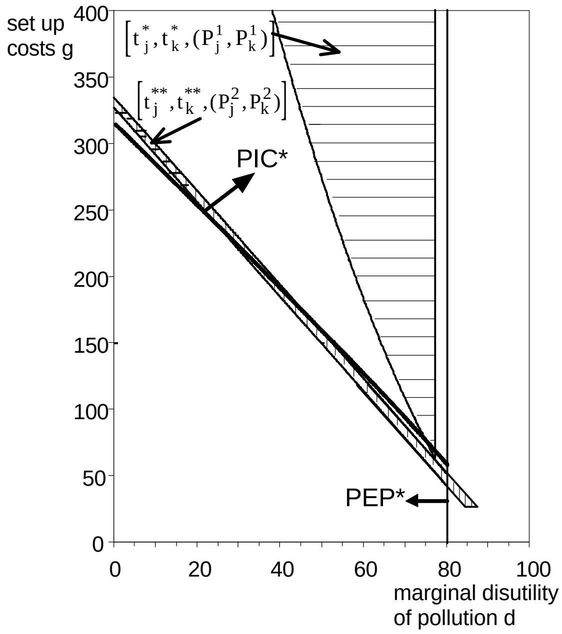


c) Parameterization: a = 120
s = 8

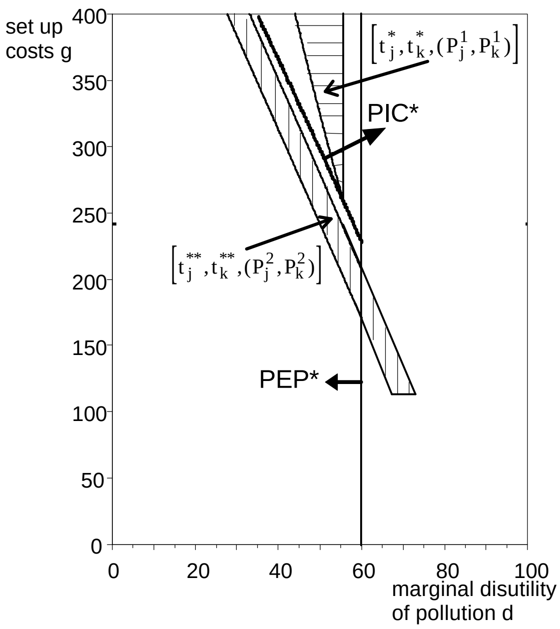
The arrows indicate the corresponding parameter regions.

Figure 3

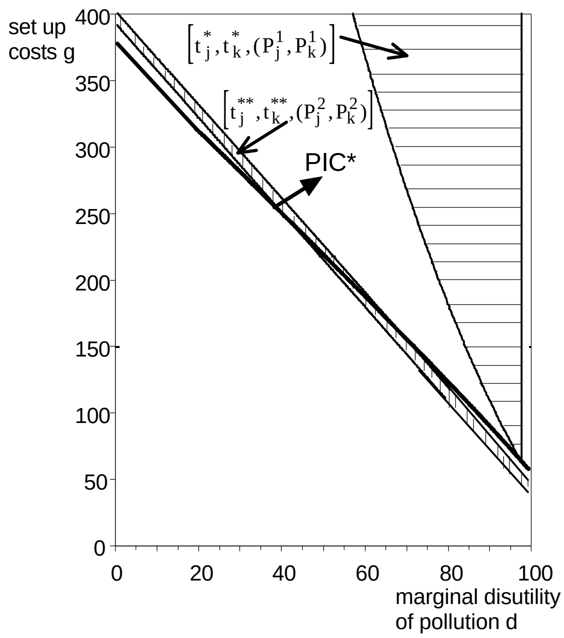
Pareto improvement by a tax coordination to t_j^*, t_k^* (PIC*)



a) Parameterization: market size a = 100
transportation costs s = 8



b) Parameterization: a =100
s = 16



c) Parameterization: a = 120
s = 8

The arrows indicate the corresponding parameter regions.