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Locational competition under environmental regulation when input prices and productivity differ

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Abstract. The purpose of the paper is to outline an analytical framework which captures the ample scope of locational competition: cost differences, resulting from differences in factor prices including taxes, human capital, infrastructure services and total factor productivity. If cost differences are small, locational competition controls excessive government power. We have modeled locational competition by assuming that governments have a vital interest to keep mobile factors of production at home. We represent this aspect by restricting the usage of environmental instruments such that they will at most exhaust the cost difference to a competing foreign firm. If cost differences are large enough there is no binding restriction for the cost-benefit calculus of a national environmental policy. The tax will be below marginal damage due to strategic reasons of rent shifting. If small international cost differences do not allow taxation in accordance with marginal damage considerations, then locational competition restricts the size of the tax rate such that the firm is indifferent in relocating or staying at home.

JEL classification: R32, R38, H23, F22

1. Introduction

It is argued in the literature that differences in environmental regulations are an important factor in industrial location (industrial flight hypothesis). This hypothesis is derived from an extension of the Heckscher-Ohlin model of comparative advantage. Since companies can avoid regulations by locating abroad, free trade erodes the independence of a country in implementing an environmental policy. This exerts a strong pressure towards lax regulation in order to signal a pollution haven to producers. Especially in the theoretical literature, multinational firms seem to base their direct foreign investment decision or plant location upon the stringency of environmental regulation in other countries (developing countries or Eastern Europe). The environmental regulation intensity is expected to be a significant determinant of competitiveness and causes industrial flight from industrialized countries. The argument is that stringent environmental standards cause high costs of production, leading to a decline in competitiveness, and ultimately in market share, jobs and investments. In countries with persistently high unemployment, threats of job losses and of plant relocation can be very powerful and helpful for opponents of a strict environmental policy.[1] However, a broad consensus has emerged in the empirical literature that regulatory differences (with some exceptions) have, at best, a negligible impact on industrial location. Studies attempting to measure the effect of environmental regulation on net exports, overall trade flows, and plant-location decisions have produced estimates that are either small or statistically insignificant. These results emerged from studies by Jaffe et al. (1995) and Adams (1997) which review the empirical evidence.[2]

We therefore will specify a model which permits the **option** to relocate but in which governments will not set environmental taxes or standards such that firms will choose this option. In this model location decisions do not only depend on regulatory differences, but also on differences in factor prices, in the quality of the labor force, access to markets, differences in corporate taxes or in the provision of infrastructure. Governments know these factors which can affect business location decisions and they also know that it is rather unlikely that firms will move to another country for the only reason of taking advantage of relatively lax environmental standards.

The purpose of this paper is to introduce international productivity gaps into a model on relocation decisions and to show that there is plenty of room for strict regulation if countries are not too similar in terms of productivity and factor price differences. With productivity gaps between countries, it is hopeless to lure business into another country by providing low environmental standards. In our special model, governments might exploit the cost advantage of their domestic firms to a certain extent by adding an environmentally motivated regulatory burden, but they will set this burden low enough such that it will not cause firms to relocate existing plants. Therefore this model is in line with a study by Bartik (1988) who found that air and water pollution control expenditures, costs of compliance, and allowed particulate emissions all have an insignificant effect on plant location decisions. Jaffe et al. (1995) summarize the reasons why the effects of environmental regulation on location decisions may be small. First, for all but the most heavily regulated industries, the cost of complying with environmental regulation is a relatively small fraction of total cost of production. Second, labor cost differentials, energy and raw materials cost differentials and infrastructure adequacy dominate the environmental cost effect. Third, other monetary-equivalent costs or benefits like public services, unionization of a country's labor force, or agglomeration effects from the existing level of manufacturing activity in a region also affect plant location choices. Fourth, since the difference in environmental regulation in western industrial countries is not large, the incentive to relocate is small. And fifth, in case significant differences in regulatory stringency exist, firms may not exploit them. Because of environmental credibility reasons firms

[1] I am grateful to the anonymous referees for helpful suggestions. See Jaffe et al. (1995) and Adams (1997) for excellent surveys on environmental regulation and competitiveness.

[2] The gap between the theoretical and empirical literature is also due to methodological weaknesses of the empirical studies (see Jeppesen et al. 1999 and Jeppesen et al. 2002 on this point).

are reluctant to build less-than-state-of-the art plants in foreign countries, or, when environmental standards are relatively weak, firms may invest more in pollution control than is required.

We will now give a short survey of the literature. The first model on location decision and environmental policy is by Markusen et al. (1993). They develop a model that allows firms to enter or exit, and to change the number and locations of their plants in response to changes in environmental policies. There are increasing returns at the plant level (fixed costs), imperfect competition between a domestic and a foreign firm, and transport costs of shipping out between two markets. The authors consider two countries and assume that one firm - not yet established at the beginning of the game - is associated with each country. Firms decide where to set up production after having observed the governments' move. The decision to serve another region is a discrete choice between the high fixed-cost option of a foreign branch plant or the high variable-cost option of exporting to that market. Decisions on plant locations are no longer based on marginal analysis but are now discrete choice problems. At critical levels of environmental policy variables, small policy changes cause large discrete jumps in a region's pollution and welfare as a firm closes or opens a plant, or shifts production to/from a foreign branch plant. They extend their model by introducing tax competition between the governments of the two regions (Markusen et al. (1995)). If the damage from pollution is high enough, the two governments will compete by increasing their environmental taxes until the polluting firm is driven from the market. Alternatively, if damage from pollution is not as high, the governments will compete by undercutting each other's pollution tax rates. Markusen et al. (1995) use numerical examples that show the range of parameters that cause a move from one equilibrium to another. Following them, Hoel (1997) also considers a two-stage game at the firm and at the government level. Under his assumption that costs of the firms, except taxes, are independent of where the firms locate, each firm will only produce in one (or none) of the two countries. Markusen et al. (1995) allow for non-zero transportation costs which implies that it may be optimal for a firm to locate in both countries in spite of its fixed costs. Hoel's somewhat simpler model makes it possible to derive some qualitative results under rather general assumptions. In the game he considers the governments of the two countries first choose their tax rates, after which the firm locates in the country with the lowest tax rate. Markusen et al. and Hoel analyze the case where environmental damage is so large that the firm does not locate in any of the countries in the Nash equilibrium (the NIMBY case (not in my backyard)). The main conclusion from the model is that on the one hand the incentive of each country to attract firms results in lower environmental taxes than it would be with cooperation. On the other hand, if disutility from pollution is sufficiently high, each country might prefer that a firm locates only in other countries. This effect tends to make environmental policy under non-cooperation stricter than it would be with cooperation. The model by Rauscher (1995) is another simplified version of Markusen et al. (1995) by neglecting transportation costs so that a single plant suffices to serve the whole market. In this paper there is one firm that wishes to establish a plant in one of n countries and the game between the countries is affected by transboundary pollution effects. It has been shown that there is a large variety of taxes ranging from zero taxes to taxes as high as to imply the NIMBY case. In Ulph (1994), several producers of a single industry have to decide where to locate plants to serve several markets. In a multi-stage game governments first choose their policies to restrict emissions of a pollutant (no strategic policy), producers then make location decisions and finally set outputs. In the paper the question is considered whether governments should offer subsidies to producers to prevent them from relocating to other countries. A rebate policy of taxes back to the industry is simulated using data for the world fertilizer industry. Ulph wants to demonstrate that relocation can change the degree of competitiveness of different markets. Producers have chosen to locate where there are economies of agglomeration so that moving into foreign markets sacrifies some of these economies. The trade-off between these economies and transport costs will be one of the factors affecting firms in their choice of plant location.

In Motta and Thisse (1994) firms are already established in their home country when the game begins. They study the impact of the home country's environmental policy on the domestic firm's location while the foreign firm's location strategy is given. The option for the domestic firm is to supply both markets from its domestic plant; or to establish a second plant in the foreign market; or to shut down the home plant and to serve both markets through the new plant set up in the foreign country. Exports imply transportation costs and environmental policy raises marginal cost. They describe the equilibrium configurations by a partition of the parameter space. The objective is to show that environmental trade barriers may cause significant welfare losses.[3] Ulph and Valentini (1997) introduce intersectoral linkages between firms in the plant location decision. By analysing the location decision of firms in different sectors which are linked through an input-output structure of intermediate production, they wish to explore the incentive for firms in different sectors to agglomerate in a single location.

Location decisions of footloose firms in response to environmental costs are also analyzed in Markusen (1999), who presents simulation results derived from a numerical general equilibrium model. In summarizing the results from the main contributions to the location topic he emphasizes that it is not at all clear that regional competition for mobile plants leads to lower standards in equilibrium.

Hübner (1998) looks at a three stage game in environmental tax competition in a two-country, two firm partial equilibrium model in which plant locations are endogenous. Similarly as in our model, Hübner neglects costs of transportation and trade barriers so that firms are not interested in setting up a multinational market structure with more than one plant. In this analysis, Hübner includes also possibilities of market structures like a monopoly if the other firm decides not to produce at all, or both firms stop to produce because taxes are too high. Both firms produce with the same technology at zero marginal cost. A conclusion from this assumption is that firms do not relocate if the tax rates are the same in both countries. Finally, in a recent paper Greaker (2003) extends the literature on strategic environmental policy by taking into account the ability of firms to relocate their production. In Greaker the firms are also symmetric; a difference in environmental standards will always lead to a relocation if costs of relocation are zero. In our model

[3] A recent discussion paper on strategic location decisions is Petrakis and Xepapadeas (2000) which analyzes delocation decisions of a monopolist who faces an emission tax in the home country.

firms may not wish to relocate in such a case because they benefit from lower factor prices at home or from a higher total factor productivity (TFP).

We want to emphasize in this paper the difference in factor prices, in TFP, or in other important location aspects on the cost of production when producing at different locations. Most authors concede that firms may change their production location for a lot of reason, but in their papers they focus only on environmental costs. We think that the interface between environmental regulation and differences in factor prices and TFP is an important issue for environmental policy by governments. We restrict our analysis to what we consider as a realistic case, i.e., we think that governments are interested in having firms at home. They are not interested in setting environmental taxes at such a high level to drive the firm out of the country. In principle, if plants are able to relocate, then government policies may be weaker or tougher than would be the case without relocation depending on whether damage costs exceed the profit tax benefits of having a firm located in a country's jurisdiction.[4] By choosing to model a policy setting by assuming that governments maximize welfare subject to a constraint not to drive the firm out of the country, we will adopt an approach of an ad hoc nature. However, we do not know of any stylized facts which show that governments would actually want to set tough environmental policies precisely to induce delocation. Cropper and Oates (1992), for example, note that despite the lack of evidence in the literature "this, of course, does not preclude the possibility that state and local officials, in **fear** of such effects (environmental regulations on the location decisions) will scale down standards for environmental quality". Since the threat of a firm to relocate is only credible if factor prices, TFP and human and infrastructure capital do not differ much between countries, it is the purpose of this paper to emphasize the underlying cost differences between countries and to model them explicitly. We do not claim that any author writing on strategic environmental policy competition ever believed that environmental policy was the only factor determining location decisions, even if their ceteris paribus assumptions implied otherwise. But the range of environmental taxes and the resulting market structure will differ significantly with differences in factor prices and TFP.

Our paper is organized as follows. In Sect. 2 we introduce the concept of productivity differences between countries as originated by Jorgenson and Nishimizu (1978), and derive a maximal environmental tax which could offset the productivity advantage of an industry making it indifferent between staying or relocating. We also introduce imperfect competition between domestic and foreign firms which differ in terms of factor prices and total factor productivity. Depending on the difference in spatial profit, they decide about the siting of their plants. In Sect. 3, we introduce environmental tax competition between two governments whereby each government is concerned about industrial migration in response to differentials in environmental taxes. In Sect. 4 we specify a translog joint cost function to see how energy taxes affect cost shares and the spatial cost differences. An empirical implementation to spatial cost gaps would permit to determine energy taxes such that firms would not wish to relocate. In Sect. 5 firms can choose among

[4] This aspect is also analyzed in Greaker (2003). He also looks at the strictness of strategic environmental policy when the governments are bounded by the threat of relocation.

n countries which makes tax competition by governments irrelevant. In Sect. 6 we describe a tax policy by a government which wishes to attract by a low tax as many firms as possible. Section 7 summarizes our conclusions.

2. Location decisions under differences in factor prices and in total factor productivity

We assume that a firm produces the quantity x of output with labor and energy and is flexible in making the decision about the site of its plant. Let D_C^i be a dummy variable with $D_C^i = 1$ if industry i is located in country $C \neq A$ and 0 otherwise where country A is the base country. Additionally let q_{L_C} denote the price of labor in country C. With country A as the base country, the price of labor $q_L\left(D_C^i\right)$ actually paid by the firm is a function of the location decision. Similarly, let the price of energy be $q_E\left(D_C^i\right) = q_E^0\left(D_C^i\right) + t\left(D_C^i\right) \cdot e$ where e is an emission coefficient, e.g. for CO_2, and t is an emission or energy tax which differs country-wise. The joint cost function then is

$$C^i = C^i\left(x_i, q_L(D_C^i),\ q_E(D_C^i),\ D_C^i\right)$$

where D_C^i as the last argument in $C(\cdot)$ represents the difference in regional factor productivity. If $\frac{\partial C^i}{\partial D_C^i} > 0$, then relocation from the base country A to country C will result in higher costs of production due to lower productivity in country C. The opposite holds if $\frac{\partial C^i}{\partial D_C^i} \leq 0$.[5] Therefore the total difference in costs if firm 1 migrates from, let us say country A to country B is

$$\frac{dC^1}{dD_B^1} = \frac{\partial C^1}{\partial x_1} \cdot \frac{dx_1}{dD_B^1} + L_1 \cdot \frac{dq_L}{dD_B^1} + E_1\left(\frac{dq_E^0}{dD_B^1} + \frac{dt}{dD_B^1} \cdot e\right) + \frac{\partial C^1}{\partial D_B^1} \tag{1}$$

where $\frac{\partial C}{\partial q_L} = L_1$, $\frac{\partial C}{\partial q_E} = E_1$ has been used (Shephard's Lemma). If $\frac{dC^1}{dD_B^1} \geq 0$, then the firm will stay in its base country A. If $\frac{dC^1}{dD_B^1}$ 0, then the firm will migrate to country B. According to (1), differences in labor costs, in energy costs, in environmental regulation and differences in total factor productivity (TFP) are determinants for a decision to relocate. We have not yet introduced relocation costs or transportation costs. Differences in infrastructure services, human capital, or R&D activities are included in the TFP difference term or could be an additional term in the cost function.[6] Since we are interested whether **new** environmental regulations will cause the firm to relocate the

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[5] In principle this is a definition since D_C^i is a discontinuous variable and thus cannot be used to form a partial derivative. Denny and Fuss (1983) showed that if we had ignored the fact that D_C^i is discontinuous, and differentiated C with respect to it we would have obtained a function of a partial derivative defined as such before.

[6] If $C = C(x, q_L, q_E, KI, D_B, \ldots, D_G)$ where KI is infrastructure, then an additional cost difference enters in (1), namely $\frac{\partial C}{\partial KI}\frac{dKI}{dD_C}$ where $\frac{\partial C}{\partial KI} < 0$ is the reduction in costs from a marginal increase in infrastructure.

existing plant, we assume that the firm produces in its base country, i.e., it is $\frac{dC^1}{dD_B^1} \geq 0$ and $\frac{dC^2}{dD_A^2} \geq 0$.

Therefore our approach emphasizes not only differences in factor prices and in environmental policy, but especially differences in national productivity. The next step is to introduce imperfect competition and environmental policy regulation in order to model the strategic interdependency of location decisions by firms and environmental policies by governments. We suppose there is a single firm in each of two countries which operates only one plant to serve the entire world market. We assume that each unit of energy used produces one unit of pollution (i.e., $e = 1$), and that there is no abatement technology. Pollution affects only the country in which the plant is located, and government in each country imposes an emission or energy tax. The structure of the moves will be that the two governments first commit themselves to a level of emission tax; then the firms decide to stay or to relocate. Besides ecological dumping as a lax environmental policy to stabilize market shares of the domestic firm, there is additional pressure on governments to relax their environmental policies if plants are able to relocate. We assume that there is a joint production process but factor prices and TFP differ by country. The corresponding fixed costs are sunk when the game begins. Hence firm 1(F1) and firm 2 (F2) do not have to take into account any fixed cost when they operate their domestic plant in country A or B. We therefore follow the approach of Motta and Thisse (1994) by assuming that firms are already established in their home country when the game begins. When firms are already established in their home country, setting up a plant abroad involves fixed set-up costs which have already been sunk in the domestic plant.

With fixed set-up costs F_1, profit of the home firm 1, F1, is

$$\pi^1 = p(x_1 + x_2)x_1 - C^1\big(x_1, q_L(D_B^1), q_E(D_B^1), D_B^1\big) - F_1 \cdot D_B^1. \tag{2}$$

Profit of the foreign firm 2, (F2), is

$$\pi^2 = p(x_1 + x_2)x_2 - C^2\big(x_2, q_L(D_A^2), q_E(D_A^2), D_A^2\big) - F_2 \cdot D_A^2 \tag{3}$$

Factor prices for F1 are:

$$\begin{aligned} q_L(D_B^1) &= q_{L_A} + (q_{L_B} - q_{L_A}) \cdot D_B^1, \quad \text{and} \\ q_E(D_B^1) &= q_{E_A} + t_A + ((q_{E_B} - q_{E_A}) + (t_B - t_A)) \cdot D_B^1. \end{aligned} \tag{4}$$

We assume that country A, the home country, is the country with lower factor prices and hence lower TFP, i.e., $\frac{dq_k}{dD_B^1} > 0,\ k = L, E$ and $\frac{\partial C^1}{\partial D_B^1}$<0. If F1 produces in A ($D_B^1 = 0$), then factor prices are q_{L_A} and $q_{E_A} + t_A$, and they are higher if F1 produces in B ($D_B^1 = 1$).

In our two country case, the factor prices for F2 are:

$$\begin{aligned} q_L(D_A^2) &= q_{L_B} + (q_{L_A} - q_{L_B}) \cdot D_A^2, \quad \text{and} \\ q_E(D_A^2) &= q_{E_B} + t_B + ((q_{E_A} - q_{E_B}) + (t_B - t_A))D_A^2 \end{aligned} \tag{5}$$

F2 produces in B ($D_A^2 = 0$) at higher factor prices and pays less for the factors if it relocates ($D_A^2 = 1$). FOCs for our duopoly are, assuming constant returns to scale, $C(x) = x_i \cdot c(\cdot)$,

$$MR^1(x_1,x_2) = c^1(q_L(D_B^1), q_E(D_B^1), D_B^1) \tag{6}$$

$$MR^2(x_1,x_2) = c^2(q_L(D_A^2), q_E(D_A^2), D_A^2).^7 \tag{7}$$

Each firm does not migrate if profit decreases after migration, i.e.,

$$\frac{d\pi^i}{dD_C^i} \leq 0 \qquad \text{or} \qquad \frac{d\pi^i}{dD_C^i} = \frac{\partial \pi_i}{\partial x_i}\frac{dx_i}{dD_C^i} + \frac{\partial \pi_i}{\partial x_j}\frac{dx_j}{dD_C^i} - x_i \frac{dc^i(\cdot, D_C^i)}{dD_C^i} - F_i \leq 0.$$

Since the first term is zero (FOC), and the second term is $p' \cdot x_i \frac{d\,x_i}{d\,D_C^i}$, the condition for non-migration is:

$$p'\frac{dx_j}{dD_C^i} - \frac{dc^i(\cdot, D_C^i)}{dD_C^i} - \frac{F_i}{x_i} \leq 0 \quad \text{or} \quad \frac{p'}{c_i}\frac{dx_j}{dD_C^i} - \frac{d\ln c^i(\cdot, D_C^i)}{dD_C^i} - s_{F_i} \leq 0 \quad (i \neq j) \tag{8}$$

where $s_{F_i} = \frac{F_i}{x_i \cdot c_i}$ is the cost share of the set-up costs. Because of Shephard's Lemma, total differentiation of $\ln \ c^i(\cdot)$ yields[8]

$$\frac{d\ln c^i}{dD_C^i} = \frac{q_{L_A} \cdot L_i}{x_i \cdot c_i}\frac{d\ln q_L}{dD_C^i} + \frac{(q_{E_A} + t_A)E_i}{x_i \cdot c_i}\frac{d\ln q_E}{dD_C^i} + \frac{\partial \ln c^i}{\partial D_C^i}. \tag{9}$$

For the rate of country-wise difference in total factor productivity we assume

$$W_{B,A} \equiv \frac{\partial \ln c^1}{\partial D_B^1} < 0 \qquad \text{and} \qquad W_{A,B} \equiv \frac{\partial \ln c^2}{\partial D_A^2} > 0. \tag{10}$$

An unit of output, produced by F1 at the lower factor prices in A, can be produced in B at lower costs because of higher TFP. An unit of output, produced by F2 at the higher factor prices in B, will be produced in A at higher costs by the same rate because TFP is lower by that rate. For firm i, the decision to relocate depends on the sign of the difference in profit, that is, using (8) and (9),

$$s_{\pi^i}\frac{d\ln \pi^i}{dD_C^i} = \frac{p'dx_j}{c_i dD_C^i} - s_{L_i}\frac{d\ln q_L}{dD_C^i} - s_{Et,i}\frac{d\ln q_E}{dD_C^i} - \frac{\partial \ln c^i}{\partial D_C^i} - s_{F_i} \tag{11}$$

where $s_{L_i} = \frac{q_{L_A} \cdot L_i}{x_i \cdot c_i}$, $s_{Et,i} = \frac{(q_{E_A} + t_A)E_i}{x_i \cdot c_i}$ and $s_{\pi^i} = \frac{\pi_i}{x_i c_i}$ are the cost shares of labor, energy and of profit.[9]

We finally determine the difference in competitor's output if a firm relocates. With demand $p = a - (x_1 + x_2)$ and constant marginal costs c_1 of firm 1

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[7] Under the assumption of a joint production process, marginal cost of both firms producing in country A is then

$$c^1(q_{L_A}, q_{E_A} + t_A, D_B^1 = 0) = c^2(q_{L_A}, q_{E_A} + t_A, D_A^2 = 1) =: c_1(q_{L_A}, q_{E_A}, t_A)$$

and when producing in country B

$$c^2(q_{L_B}, q_{E_B} + t_B, D_A^2 = 0) = c^1(q_{L_B}, q_{E_B} + t_B, D_B^1 = 1) =: c_2(q_{L_B}, q_{E_B}, t_B).$$

[8] The notation q_{E_A}, t_A, q_{L_A} is correct if $i = 1$ and reads q_{E_B}, etc. if $i = 2$.

[9] Following Jorgenson and Nishimizu (1978), the productivity term can be calculated as a residual: $\frac{\partial \ln c}{\partial D_C} = \frac{d\ln c}{dD_C} - \sum_{k=L,E} \bar{s}_k \frac{d\ln q_k}{dD_C}$ where $\bar{s}_k$ are the average cost shares of the two countries.

and c_2 of firm 2 we get equilibrium outputs $x_1^* = (a + c_2 - 2c_1)/3$ and $x_2^* = (a + c_1 - 2c_2)/3$. If firm 1 moves to country B, equilibrium outputs change to $\tilde{x}_1 = \tilde{x}_2 = (a + c_2 - 2c_2)/3$ since then $c_1 = c_2$. If firm 2 moves to country A, equilibrium outputs change to $\tilde{x}_1 = \tilde{x}_2 = (a + c_1 - 2c_1)/3$. Hence it is

$$\frac{d\,x_j}{d\,D_C^i} = \frac{1}{3}\left(c_j - c_i\right) = \frac{1}{3}\,\frac{d\,c^i}{d\,D_C^i}$$

Therefore, the difference in profits in (11) is:

$$\begin{aligned} s_{\pi^i}\frac{d\ln\,\pi^i}{d\,D_C^i} &= -\frac{1}{3}\;\frac{d\,\ln\,c^i}{d\,D_C^i} - \frac{d\ln c^i}{dD_C^i} \\ &\quad - s_{F_i} = -\frac{4}{3}\left(s_{L_i}\,\frac{d\,\ln\,q_L}{d\,D_C^i} + s_{Et,i}\,\frac{d\,\ln\,q_E}{d\,D_C^i} + \frac{\partial\,\ln\,c^i}{\partial\,D_C^i}\right) - s_{F_i} \end{aligned} \tag{12}$$

since $p' = -1$.

There are four possible cases of market structure, illustrated by the following pay-off matrix:

firm2

		$D_A^2 = 0$	$D_A^2 = 1$
	$D_B^1 = 0$	$\pi_A^1 \quad \pi_B^2$	π_A^{1*} $\pi_A^2 = \pi_A^{1*} - F_2$
firm1	$D_B^1 = 1$	$\pi_B^1 = \pi_B^{2**} - F_1$ π_B^{2**}	$\pi_B^1 = \pi_B^2 - F_1$ $\pi_A^2 = \pi_A^1 - F_2$

Only three cases could be a Nash-equilibrium in pure strategies because the case in the lower right hand side corner can not occur because an exchange of the initial locations can not be of advantage for both firms.

Case $D_B^1 = 0, D_A^2 = 0$: Each firm stays in its own country; i.e., $\frac{d\,\pi^i}{d\,D_C^i} \leq 0$ for $i = 1, 2$. Differences in competitor's output, in factor prices net of differences in TFP, given fixed set-up costs can not motivate the firms to relocate.

Case $D_B^1 = 1, D_A^2 = 0$: Firm 1 migrates to B, firm 2 stays in B; i.e., $\frac{d\,\pi^1}{d\,D_B^1} > 0, \frac{d\,\pi^2}{d\,D_A^2} \leq 0$.

Case $D_B^1 = 0, D_A^2 = 1$: Firm 1 stays in A, firm 2 migrates to A; i.e., $\frac{d\,\pi^1}{d\,D_B^1} \leq 0, \frac{d\,\pi^2}{d\,D_A^2} > 0$.

Let us summarize our results. Since the production technology is by assumption the same, relocation of one firm yields symmetric Nash equilibria because both firms produce with the same productivity at the same factor prices. Relocation of both firms is not an equilibrium because after migration each firm produces at conditions identical to those of the firm which migrated because of these conditions. It would therefore return to its previous location;

i.e., it would stay there. Finally, not to relocate yields an asymmetric Nash-equilibrium.

3. Tax competition without causing relocation

The government of A maximizes welfare with respect to an emission tax t_A where welfare is the sum of profit and "environmental surplus" (tax revenue minus damage DA): [10]

$$\max_{t_A} \; w_A = \pi^1(\cdot) + t_A \cdot E(\cdot) - DA_A(E(\cdot)) \tag{13}$$

where $(\cdot) = \left(D_B^1, D_A^2\right)$, subject to the condition that the domestic firm F1 does not relocate, i.e. according to (12):

$$s_{\pi^1} \frac{d \ln \pi^1}{dD_B^1} = -\frac{4}{3}\left(s_{L,1} \frac{d \ln q_L}{dD_B^1} + s_{E,1} \frac{d \ln q_E^0}{dD_B^1} + s_{t,1} \frac{d \ln t}{dD_B^1} + \frac{\partial \ln c^1}{\partial \, D_B^1} \right) - s_{F_1} \leq 0 \tag{14}$$

where $s_{E,1} = \frac{q_{E_A} \cdot E_1}{x_1 \cdot c_1}$, and $s_{t,1} = \frac{t_A \cdot E_1}{x_1 \cdot c_1}$. We assume that (14) was satisfied before the introduction of an emission tax or of a tax increase. The home government can then raise t_A, implying $d^2t \big/ dD_B^1 dt_A 0$, until the cost disadvantage, when relocating, is exhausted.

It is argued that the drawback of a measure of welfare used here is that it does not account for possible job losses associated with a partial or total delocation (Motta and Thisse 1994). I personally would, however, interpret profit not as a tax base for the government or as an income flow to the shareholders but positive profits as a signal that a firm exists which creates jobs. If a firm makes profit abroad, it is irrelevant for the welfare measure to add a term which represents the percentage of repatriated profit.[11] If a firm delocates, jobs are lost which is more important for the country than lost profit. Our restriction (14) expresses the interest of governments not to regulate such that jobs are lost due to delocation. A direct interest in jobs by the government could be modeled by including the revenue from a tax t_L on labor in the objective function. Then the objective of the government is

$$\max_{t_A} \quad w_A = \pi^1(\cdot) + t_A \cdot E(\cdot) + t_L \cdot q_{L_A} \cdot L(\cdot) - DA_A(E(\cdot)). \tag{15}$$

The monetary weight $t_L \, q_L$ could also be interpreted as a shadow price or political welfare evaluation assigned to an employed person in the industry.

Similarly, government in B chooses t_B to maximize welfare subject to the condition that F2 stays in B:

$$\max_{t_B} \quad w_B = \pi^2(\cdot) + t_B \cdot E(\cdot) + t_L \cdot q_{L_B} \cdot L(\cdot) - DA_B(E(\cdot)) \tag{16}$$

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[10] In principle, the total value of the objective function has to be multiplied by $(1 - D_B^1)$ because if the firm moves to B, welfare in A is zero.

[11] See Motta and Thisse (1994). In Greaker (2000), a tax rate on profit is introduced which implies that a government looses a part of the profit when it allows relocation of its firm. If the firm relocates, the non-taxed part of the profit is transferred back to the country through the ownership which still is located in the country.

subject to

$$s_{\pi^2}\frac{d\ln\pi^2}{dD_A^2} = -\frac{4}{3}\frac{d\ln c^2}{dD_A^2} - s_{F_2} = -\frac{4}{3}\left(s_{L,2}\frac{d\ln q_L}{dD_A^2} + s_{E,2}\frac{d\ln q_E^0}{dD_A^2}\right.$$
$$\left. + s_{t,2}\frac{d\ln t}{dD_A^2} + \frac{\partial \ln c}{\partial D_A^2}\right) - s_{F_2} \le 0. \qquad (17)$$

Since (14) and (17) are satisfied, i.e., firm 1 stays in country A and firm 2 in country B, D_B^1 and D_A^2 are equal to zero in the objective functions (13) and (16). The government of country A therefore maximizes

$$\max_{t_A}\ w_A = p\,(x_1 + x_2)\,x_1 - x_1 \cdot c_1(q_{L_A}, q_{E_A} + t_A)$$
$$+ t_A \cdot E_1 + t_L \cdot q_{L_A} \cdot L_1 - DA_A(E_1) \quad s.t. \qquad (14).$$

and the government of country B[12]

$$\max_{t_B}\ w_B = p(x_1 + x_2)\,x_2 - x_2 \cdot c_2(q_{L_B}, q_{E_B} + t_B)$$
$$+ t_B \cdot E_2 + t_L \cdot q_{L_B} \cdot L_2 - DA_B(E_2) \quad s.t. \qquad (17).$$

For characterizing the optimum we consider the local Kuhn-Tucker conditions. The Lagrange function for A is:

$$\mathscr{L}(t_A, \lambda) = \pi_1(x_1(t_A, t_B), x_2(t_A, t_B), t_A) + t_A \cdot E_1 + t_L \cdot q_{L_A} \cdot L_1 - DA_A(E_1) +$$
$$\lambda\left[-\frac{4}{3}\frac{d\ln\ c^1(t_A, t_B, D_B^1)}{dD_B^1} - s_{F_1}\right].$$

The conditions for an optimal solution $\hat{t}_A$, given t_B, are (it is $\pi_{x_1} = 0$, the FOC of the firm):

$$\mathscr{L}_{t_A} = \frac{\partial\,\pi_1}{\partial\,x_2}\frac{\partial\,x_2}{\partial\,t_A} + t_L \cdot q_{L_A} \cdot \frac{\partial\,L_1}{\partial\,t_A} + (t_A - MDA_A) \cdot \frac{\partial\,E_1}{\partial\,t_A}.$$
$$+ \lambda \cdot \frac{\partial}{\partial\,t_A}\left[-\frac{4}{3}\ \frac{d\ \ln\ c^1(t_A, t_B, D_B^1)}{d\ D_B^1} - s_{F_1}\right] \le 0 \qquad (18)$$

It is $MDA_A = \frac{dDA_A}{dE_1}$ the marginal damage due to emissions from burning fossil fuel E. In addition, restriction (14) must be satisfied, i.e.,

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[12] We could extend, in principle, our model by introducing transboundary pollution or global pollution. Transboundary pollution implies that foreign emissions also have an impact on national damage. The damage function from total pollution TE_A (proportional to fossil fuel E) is $DA_A(TE_A)$ where total pollution depends on the level of the pollution-intensive inputs and on the share of domestic pollution leaving the country and on the share of foreign pollution entering the country $(0 \le s_A \le 1,\quad 0 \le s_B \le 1)$. Hence total pollution is $TE_A = (1 - s_A) \cdot E_1 + s_B \cdot E_2$, and similarly for $TE_B = (1 - s_B) \cdot E_2 + s_A \cdot E_1$. For global pollution $TE_i = E_1 + E_2,\quad i = A, B$. This extension would add an additional strategic aspect to the ample scope of locational competition, however, on the cost of more complex mathematics. Since the conclusions of the paper would be similar (see the strategic trade policy under global pollution (Conrad 1993) and under transboundary pollution (Conrad 1997), we have dropped this extension.

$$\mathscr{L}_\lambda = -\frac{4}{3}\,\frac{d\ln c^1}{dD_B^1} - s_{F_1} \le 0 \tag{19}$$

Additional conditions are

$$t_A \cdot \mathscr{L}_{t_A} = 0 \tag{20}$$

$$\lambda \cdot \mathscr{L}_\lambda = 0. \tag{21}$$

Let us first consider the case when $\hat{\lambda} = 0$ is a solution. Then the inequality (14) need not be binding at the optimal tax $\hat{t}_A$; i.e., it is $-\frac{4}{3}\,\frac{d\ln c^1(\hat{t}_A;t_B)}{dD_B^1} - s_{F_1} < 0$ and the domestic location is not endangered at $\hat{t}_A$. The structure of the tax can be derived from the implicit reaction function (18):

$$\hat{t}_A = MDA_A - \frac{\frac{\partial \pi_1}{\partial x_2}\frac{\partial x_2}{\partial t_A} + t_L \cdot q_{L_A} \cdot \frac{\partial L_1}{\partial t_A}}{\frac{\partial E_1}{\partial t_A}}. \tag{22}$$

This is the strategic tax of the type $\hat{t}_A < MDA_A$ because of $\frac{\partial \pi_1}{\partial x_2} < 0$, $\frac{\partial x_2}{\partial t_A} > 0$, $\frac{\partial L_1}{\partial t_A} < 0$ and $\frac{\partial E_1}{\partial t_A} < 0$.[13] The sign of $\frac{\partial L_1}{\partial t_A}$ is in principle ambiguous. It is

$$\frac{\partial L_1}{\partial t_A} = \frac{\partial L}{\partial x_1}\quad\frac{\partial x_1}{\partial t_A} + \frac{\partial L}{\partial q_{E_A}}.$$

If we assume that the negative output effect on labor demand from a higher tax dominates the positive substitution effect on labor (second term) from the tax induced increase in energy prices, then $\partial L_1/\partial t_A$ is negative. Computable general equilibrium analyses in the context of the double dividend hypothesis have shown that the negative output effect is stronger than the positive substitution effect even if the tax revenue is used to reduce non-wage labor cost. Under our assumption of weak substitution between energy and labor, the strategic effect in (22) is enforced by the concern of the government that jobs lost due to a lower output level imply less revenue from the labor tax.

If $\hat{\lambda} > 0$, then (21) and (19) (as equation) imply a tax rate t_A^* to prevent migration. Since marginal damage is high, the tax should be high but only such that the firm is indifferent between staying and relocating. Since $t_A^* > 0$ in (20), a system of two equations in t_A and λ has to be solved, namely (14) and (18) as equations. From (14) follows that the magnitude of the tax is such that the difference in the tax rates makes up for the advantage in the cost of production:

$$-s_{t,1}\;\frac{t_B - t_A}{t_A} = s_{L,1}\frac{d\ln\,q_L}{dD_B^1} + s_{E,1}\;\frac{d\ln q_E^0}{dD_B^1} + \frac{\partial \ln c^1}{\partial D_B^1} + \frac{3}{4}s_{F_1}. \tag{23}$$

By solving (23) for t_A we obtain

$$t_A^* = t_B + q_{E_A}\left(s_{L,1}\frac{d\ln q_L}{dD_B^1} + s_{E,1}\frac{d\ln q_E^0}{dD_B^1} + \frac{\partial \ln c^1}{\partial D_B^1} + \frac{3}{4}s_{F_1}\right)\Big/ s_{E,1}. \tag{24}$$

[13] A tax below marginal damage is well known from the literature (see e.g. Barrett 1994 and Conrad 1993). From differentiating (6) and (7) totally we know that $\frac{\partial x_1}{\partial t_A} < 0$ and $\frac{\partial x_2}{\partial t_A} > 0$; a higher tax reduces the market share of F1.

Because of our assumption of constant returns to scale, the cost shares are independent of output x_1. If we assume in addition that the cost shares do not depend on energy prices (a Cobb Douglas production function, for example), then (24) is linear in t_A and t_B (provided the productivity difference does not depend on the taxes). From (24) we then conclude, that the higher the energy tax in country B, the higher t_A can be set as an upper limit to prevent relocation. The same argument holds if the prices of labour and/or energy are much higher in country B. Because of $\partial \ln c^1/\partial D_B^1 < 0$, high TFP in country B limits the level of the energy tax. Finally, if set-up costs are high, the critical level of the tax rate can be higher.

By assuming, for example, that marginal damage is high in B, implying in principle a high tax t_B such F2 would relocate, we obtain the analogous case with t_B^* as a function of t_A, and a $\hat{\lambda} > 0$. From (17), using $\frac{dt}{dD_A^2} = t_A - t_B$, we obtain

$$t_B^* = t_A + q_{E_B}\left(s_{L,2}\frac{d\ln q_L}{dD_A^2} + s_{E,2}\frac{d\ln q_E^0}{dD_A^2} + \frac{\partial \ln\ c^2}{\partial D_A^2} + \frac{3}{4}s_{F_2}\right)\Big/ s_{E,2} \tag{25}$$

Two types of equilibrium could emerge from our analysis. An equilibrium of type (i) is obtained if both emission taxes are not high enough to affect location decisions. The Nash- equilibrium in tax rates $(\hat{t}_A, \hat{t}_B)$ can be found by solving (22) and the corresponding implicit reaction function for government B for the tax rates. In order to characterize this and the other types of equilibrium it might be useful to take a look at Fig. 1. The figure depicts the reaction functions $t_A = R_A(t_B)$ and $t_B = R_B(t_A)$ and the equilibrium tax rates $(\hat{t}_A, \hat{t}_B)$ at their intersection. Besides this type (i) equilibrium there could emerge two type (ii) equilibria characterized by a binding non-relocation

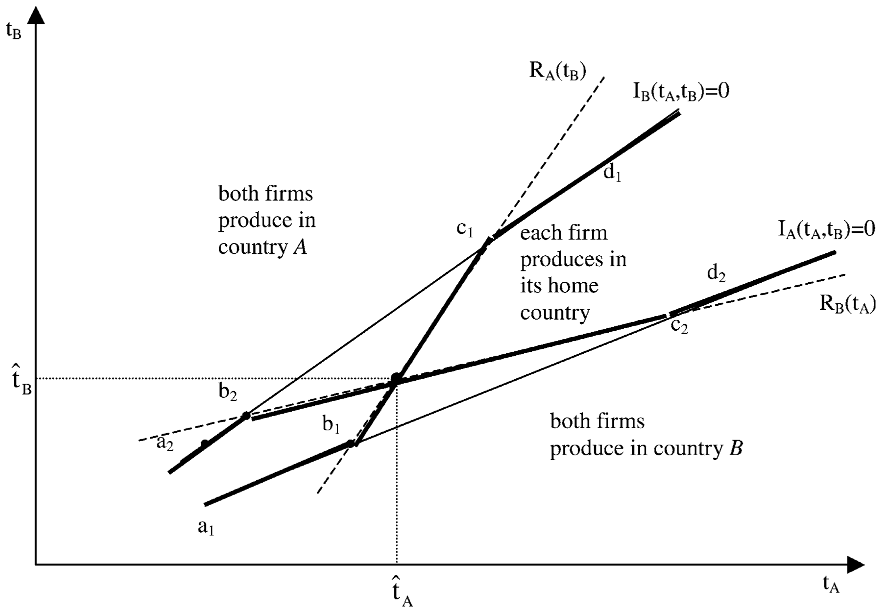

Fig. 1. Equilibrium of strategic emission taxes $(\hat{t}_A, \hat{t}_B)$ at tax levels which do not endanger relocation

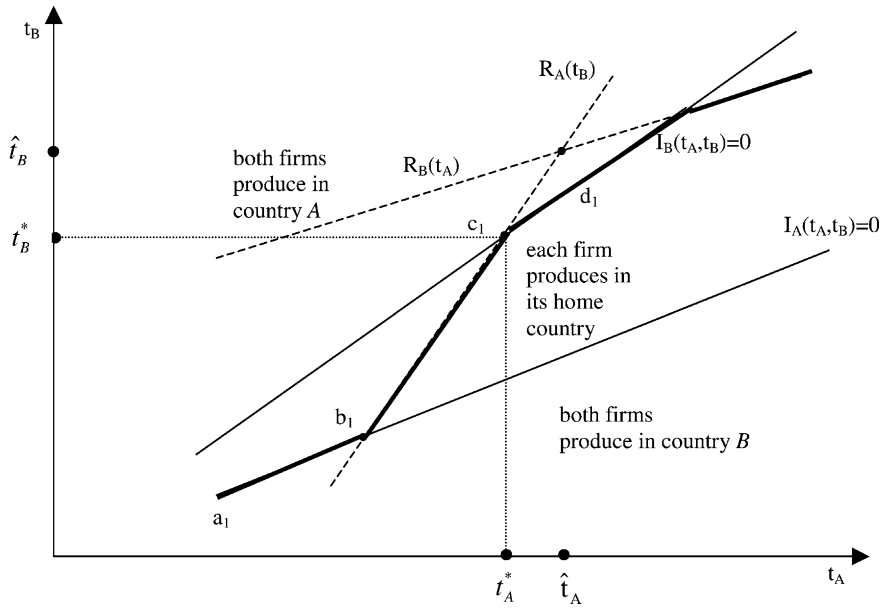

Fig. 2. Equilibrium of strategic emission taxes $\left(t_A^*, t_B^*\right)$ at tax levels which make firm 2 indifferent of staying or of relocating

restriction. These types of equilibrium are characterized by two curves, one being an indifference condition of the home firm and the other being an analogous condition for the foreign firm. Let us briefly devote these conditions $I_A(t_A, t_B) = 0$ for (14) as equation and $I_B(t_A, t_B) = 0$ for (17) as equation. The equation $I_A(t_A, t_B)$ thus describes all pairs of tax rates that leave the home firm indifferent between staying in country A or relocating to country B. Fig. 1 depicts the firms indifference curves. We note that the reaction functions are meaningful only within the sections between the two indifference curves where each firm produces in its home country.

From these three curves $(I_A(t_A, t_B) = 0,\ I_B(t_A, t_B) = 0,\ R_A(t_B))$ can the best reply function of the government in country A be derived. Under our assumption, government in A restricts the usage of the tax rate t_A such that its firm produces in its home country. The best reply function of government in A is then given by the curve $a_1\, b_1\, c_1\, d_1$. Within the section $a_1 b_1$ $[c_1 d_1]$ of this curve the government takes care of the fact that firm 1 [2] would relocate should the government choose its preferred tax rate. If the government ignores its influence on the location decision of firm 2, then the part $b_1 c_1$ of the reaction function will have no kink in c_1. We get an analogous best reply function for the government in B. If countries are asymmetric, a tax equilibrium $(\hat{t}_A, \hat{t}_B)$ might occur.

Compared to Fig. 1 we have assumed in Fig. 2 that marginal damage is higher in country B than in country A. A Nash-equilibrium $(\hat{t}_A, \hat{t}_B)$ would imply a tax rate $\hat{t}_B$ such that firm 2 relocates. The equilibrium occurs at the intersection of $I_B(t_A, t_B)$ and $t_A = R_A(t_B)$ at the tax rates t_A^* and t_B^*. The second equilibrium of type (ii) occurs if we shift $R_A(t_B)$ in Fig. 1 to the right such that the Nash-equilibrium requires a tax rate $\hat{t}_A$ which induces relocation of firm 1. Now the equilibrium occurs at the intersection of $R_B(t_A)$ and $I_A(t_A, t_B)$.

We could think in addition of an equilibrium of type (iii) which is characterized by the intersection of the firms's indifference conditions $I_A(t_A, t_B) = 0$ and $I_B(t_A, t_B) = 0$. This equilibrium could be the outcome of a situation where marginal damages are high in both countries so that both governments will set the tax rates to their upper limit. However, this type of equilibrium fails to exist (each government sets taxes such that its domestic firm is indifferent between staying and relocating).[14]

Let us summarize the features of our two-stage game. The governments know the Nash solutions of the game of the firms in quantities $x_1(t_A, t_B)$ and $x_2(t_A, t_B)$. They compete at the first stage in taxes to control the environmental externality by mitigating at the same time the loss of market shares to foreign competitors and by preventing the relocation of its firms. We obtained two types of equilibrium. If marginal damage does not require a tax which drives the firm out of the country, then governments set strategic taxes below marginal damage, the eco-dumping case. Solving the implicit reaction functions (22), $\hat{t}_A = r_A(t_B)$, and the analogous function $\hat{t}_B = r_B(t_A)$, a Nash equilibrium in tax rates can be derived. A second type of equilibrium occurs if t_A is modest and F1 will stay in the country. Equation (22) is then the relevant implicit reaction function. But in B the tax t_B is high and set at a level such that F2 is indifferent between staying or migrating. The response on t_A is determined by $I_B\left(t_A, t_B^*\right) = 0$, i.e. by (25). Solving these two "implicit reaction functions" for t_A and t_B yields an equilibrium, providing it exists and is unique.[15]

4. A parametric approach to spatial cost gaps

To better understand our approach it might be useful to choose a specification of the unit cost function, e.g. a translog function with constant returns to scale:

$$\begin{aligned}\ln c^1 =& \alpha_1 + \alpha_{D_B} \cdot D_B + \left(\alpha_L + \beta_{L,D_B} \cdot D_B\right) \ln q_L + \left(\alpha_E + \beta_{E,D_B} \cdot D_B\right) \ln(q_E + t) \\ &+ \frac{1}{2}\beta_{LL}\left(\ln\left(\frac{q_L}{q_E + t}\right)\right)^2 \end{aligned} \tag{26}$$

where the following parameter restrictions hold for $c(\cdot)$ to be homogeneous of degree one in the factor prices:

$$\alpha_L + \alpha_E = 1 \qquad\qquad \beta_{L,D_B} = -\beta_{E,D_B}. \tag{27}$$

The difference in productivity $W_{B,A}$ appearing in (9), i.e. the cost efficiency gap per unit of output, is defined as

[14] In (14) and (17), both written as $I_C(t_A, t_B) = 0$, the only tax term is the difference $t_B - t_A$. In (14) it is $s_{t,1}\,\frac{d\ \ln\ t}{d\ D_B^1} = s_{t,1}\,\frac{t_B - t_A}{t_A} = \frac{s_{E,1}\cdot(t_B - t_A)}{q_{E_A}}$ and in (17) it is $s_{t,2}\,\frac{d\ \ln\ t}{d\ D_B^1} = s_{t,2}\,\frac{t_A - t_B}{t_B} = -\frac{s_{E,2}\cdot(t_B - t_A)}{q_{E,B}}$. If $t_B - t_A$ solves one equation, it can not solve the other independent equation as well.

[15] Our case with indifference, i.e., $\frac{4}{3}\frac{d\ln c^1}{dD_B^1} + s_{F_1} = 0$, is characterized in the literature (e.g. Ulph 1997) by a level of an emission tax at which it would pay the firm to shut down production. This $t_A = T$ effectively acts as an upper limit on the tax rates.

$$W_{B,A} = \frac{1}{2}\left(\frac{\partial \ln c^1}{\partial D}\bigg|_{D=D_B} + \frac{\partial \ln c^1}{\partial D}\bigg|_{D=D_A}\right). \tag{28}$$

In terms of the parameters of the cost function this cost gap has the following form:

$$W_{B,A} = \alpha_{D_B} + \frac{1}{2}\beta_{L,D_B}\left[\ln\left(\frac{q_L}{q_E+t}\right)^B + \ln\left(\frac{q_L}{q_E+t}\right)^A\right]. \tag{29}$$

This equation has been obtained by differentiating (26) with respect to D_B, ignoring the fact that D_B is not a continuous variable.[16]

Finally, for the firm in country C we obtain from Shephard's Lemma the cost share equations

$$\begin{aligned} s^C_{L,1} &= \alpha_L + \beta_{L,D_B}\cdot D_B + \beta_{LL}\ln\left(\frac{q_L}{q_E+t}\right)^C \\ s^C_{Et,1} &= \alpha_E + \beta_{E,D_B}\cdot D_B - \beta_{LL}\ln\left(\frac{q_L}{q_E+t}\right)^C \end{aligned} \tag{30}$$

with $C = A \;\; (D_B = 0)$ or $C = B \;\; (D_B = 1)$.

The joint technology per product in the two countries shows up in the common β-parameters for the input prices. The α-parameters will be corrected, however, in their levels by the dummy parameters. As prices are normalized to be unity at the midpoint of yearly (monthly) observations, the α-parameters can be interpreted as average cost shares or average cost gaps. The parameter β_{L,D_B} and β_{E,D_B} measure the difference in the cost share w_L (w_E) between firm 1 and firm 2 holding prices fixed. For an interpretation as a measure of the country bias of input $L(E)$, we derive from the cost share equation the measure

$$\varepsilon_{L,D_B} = \frac{\partial \ln L}{\partial D_B} = \frac{\beta_{L,D_B}}{s^A_{L,1}} + W_{B,A}. \tag{31}$$

ε_{L,D_B} is the rate of change of input L between the firm in country A and the one in country B. If the country bias is labour saving $\left(\beta_{LD_B} < 0\right)$, a cost advantage of country B $\left(W_{B,A} < 0\right)$ is higher for input L, namely by the rate $\beta_{L,D_B}/s^A_L$. The firm (F1) requires less of all inputs at a rate $W_{B,A}$, when it

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[16] The justification for this procedure is the generalization of Diewert's (1976) Quadratic Lemma to discrete variables by Denny and Fuss (1983). In order to calculate an index (Törnquist index) for the difference in cost, $W_{B,A}$, we employ the basic efficiency accounting equation by Denny and Fuss (1983):

$$\begin{aligned} \ln c_B - \ln c_A =& \frac{1}{2}\left(\frac{\partial \ln c^1}{\partial D}\bigg|_{D=D_B} + \frac{\partial \ln c^1}{\partial D}\bigg|_{D=D_A}\right)(D_B - D_A) \\ &+ \sum_{i=L,E}\frac{1}{2}\left(\frac{\partial \ln c^1}{\partial \ln q_i}\bigg|_B + \frac{\partial \ln c^1}{\partial \ln q_i}\bigg|_A\right)\cdot\left(\ln q_{i_B} - \ln q_{i_A}\right) \end{aligned}$$

where $D_A = 0$ and hence $D_B - D_A = 1$. Solving (30) for $W_{B.A}$ yields the difference in unit cost, i.e., the discrete version of (9) (see Conrad 1989 for more details).

relocates to B, however, differentiated by the bias term. If the country bias is input L using $\left(\beta_{LD_B} > 0\right)$, firm 1 uses less inputs when producing in B, but adjusted upward for input L.

Due to symmetry (i.e. $\beta_{j,D_B} = \beta_{D_B,j}$), the parameter for the country bias permits the derivation of the change in the gap, if in a bilateral comparison the average input price $\bar{q}_j, j = L, E$ changes in (29):

$$\frac{\partial\, W_{B,A}}{\partial\, \ln q_j} = \beta_{j,D_B}.$$

If the country bias is input j saving, i.e. $\beta_{j,D_B} < 0$, then the difference in cost decreases with the average price of the corresponding input. For firm 2, located in B, we obtain analogous expressions. Its cost function is

$$\begin{aligned}\ln c^2 = {} & \alpha_1 + \alpha_{D_B}\left(1 - D_A^2\right) + \alpha_L + \left(\beta_{L,D_B}\left(1 - D_A^2\right)\right)\ln q_L + \alpha_E \\ & + \beta_{E,D_B}\left(1 - D_A^2\right)\ln(q_E + t) + \frac{1}{2}\beta_{LL}\left(\ln\left(\frac{q_L}{q_E + t}\right)\right)^2\end{aligned}$$

It is $W_{B,A} = -W_{A,B}$ (set $\ln\ c^2$ in (28)) and in terms of the parameters of the cost function we obtain:

$$W_{A,B} = -\alpha_{D_B} - \frac{1}{2}\beta_{L,D_B}\left[\ln\left(\frac{q_L}{q_E + t}\right)^B + \ln\left(\frac{q_L}{q_E + t}\right)^A\right]$$

The cost shares are:

$$s_{L,2} = \alpha_L + \beta_{L,D_B}\left(1 - D_A^2\right) + \beta_{LL}\ln\left(\frac{q_L}{q_E + t}\right)^B$$

$$s_{Et,2} = \alpha_E + \beta_{E,D_B}\left(1 - D_A^2\right) - \beta_{LL}\ln\left(\frac{q_L}{q_E + t}\right)^B.$$

We now return to our problem (13) subject to (14) and assume that t_B is so low that (14) is a binding restriction, i.e.

$$s_{L,1}\frac{d\ln q_L}{dD_B^1} + s_{Et,1}\frac{d\ln\ (q_E + t_A)}{dD_B^1} + \frac{\partial \ln c^1}{\partial D_B^1} + \frac{3}{4}s_{F_1} = 0$$

Using the equations for the cost shares yields:

$$\begin{aligned}&\left(\alpha_L + \beta_{LL}\ln\left(\frac{q_L}{q_E + t_A}\right)\right)\frac{d\ln q_L}{dD_B^1} + \left(\alpha_E - \beta_{LL}\ln\left(\frac{q_L}{q_E + t_A}\right)\right)\frac{d\ln(q_E + t_A)}{dD_B^1} \\ &\quad + \alpha_{D_B} + \frac{1}{2}\ \beta_{L,D_B}\left[\ln\left(\frac{q_L}{q_E + t}\right)^B + \ln\left(\frac{q_L}{q_E + t}\right)^A\right] + \frac{3}{4}s_{F_1} = 0\end{aligned}$$

Using $\alpha_E = 1 - \alpha_L$, this equation becomes:

$$\begin{aligned}&\left(\alpha_L + \beta_{LL}\ln\left(\frac{q_L}{q_E + t_A}\right)\right)\ \frac{d\ln q_L}{dD_B^1} \\ &+ \left[1 - \left(\alpha_L + \beta_{LL}\ \ln\ \frac{q_L}{q_E + t_A}\right)\right]\ \frac{1}{q_E + t_A}\ \left(\frac{dq_E}{dD_B^1} + t_B - t_A\right) \\ &\quad + \alpha_{D_B} + \frac{1}{2}\beta_{L,D_B}\left[\ln\left(\frac{q_L}{q_E + t}\right)^B + \ln\left(\frac{q_L}{q_E + t}\right)^A\right] + \frac{3}{4}s_{F_1} = 0\end{aligned}$$

If the country bias is labour saving and energy using (i.e. $\beta_{L,D_B} < 0, \beta_{E,D_B} > 0$ because of $\beta_{L,D_B} = -\beta_{E,D_B}$) then t_A can be set higher because firm 1 requires more inputs after relocation, especially of the taxed energy input. If the joint production process is Cobb-Douglas, then $\beta_{LL} = 0$ and t_A has to solve:[17]

$$\frac{\alpha_E}{q_E + t_A}(t_A - t_B) = \alpha_L \frac{d \ln\ q_L}{d\ D_B^1} + \frac{\alpha_E}{q_E + t_A}\frac{d\ q_E}{d\ D_B^1} + W_{B,A} + \frac{3}{4} s_{F_1}$$

If fixed costs of relocation are high (s_{F_1}), then the tax t_A can be high. If factor prices are much higher in country B ($\frac{d\ q_L}{d\ D_B^1} > 0, \quad \frac{d\ q_E}{d\ D_B^1} > 0$ by assumption) then t_A can be high. Finally, if the country-wise difference in TFP is high ($\alpha_{D_B} < 0$ by assumption), t_A cannot be set at a high level.

5. A duopoly with multi-location options

We still consider two firms which produce a homogeneous good for the world market with $p = p(x_1 + x_2)$ as the inverse demand function. They can, however, choose among n locations where to produce their output level $x_i, \quad i = 1, 2$. In that case, firm 1 maximizes

$$\max_{x_1} \pi_1 = p(x_1 + x_2)x_1 - C^1\big(x_1, q_L(D^1_{-A}), q^0_E(D^1_{-A}) + t\ (D^1_{-A}), D^1_{-A}\big) - \sum_{c \neq A}^{G} D^1_c \cdot F_{1,c}$$

where $D^1_{-A} := (D^1_B, D^1_C, \ldots, D^1_G)$. Similarly, firm 2 maximizes

$$\max_{x_2}\ \pi_2 = p(x_1 + x_2)x_2 - C^2\big(x_2, q_L(D^2_{-B}), q^0_E(D^2_{-B}) + t\ (D^2_{-B}), D^2_{-B}\big) - \sum_{c \neq B}^{G} D^2_c \cdot F_{2,c}$$

where $D^2_{-B} := (D^2_A, D^2_C, \ldots, D^2_G)$. The firms can produce at any location; if they produce at home, then D^1_{-A} and D^2_{-B} are zero-vectors. If firm 1 produces at location F, then $D^1_F = 1$ and $D^i_c = 0$ for $c \neq F$. Fixed costs $F_{i,c}$ differ among locations because of differences in distance, prices for land or financial conditions. The two FOC are (i = 1, 2):

$$MR_1(x_1, x_2) = c\big(q_L(D^1_{-A}), q^0_E(D^1_{-A}) + t\ (D^1_{-A}), D^1_{-A}\big)$$

$$MR_2(x_1, x_2) = c\big(q_L(D^2_{-B}), q^0_E(D^2_{-B}) + t(D^2_{-B}), D^2_{-B}\big).$$

The equilibrium output levels can be written as $x_i(t(D^i_{-A}), t\ (D^i_{-B}))$. Given the differences in factor prices, governments in A or B can influence profit, market share and location decision by choosing t, knowing the difference in regional tax rates, i.e., $t(D^i_{-A}) = t_A + \sum_{c \neq A} (t_c - t_A) \cdot D^i_c$. Similar to (8), the non-migration condition is, e.g., for firm 1:

[17] Written in cost shares, this equation is identical to (24).

$$\frac{d\,\pi^1}{d\,D_C^1} = p'\,\frac{d\,x_2}{d\,D_c^1} - \frac{d}{d\,D_c^1}\,\left(c^1(q_L(D_{-A}^1), q_E(D_{-A}^1), D_{-A}^1)\right) \\ -\frac{F_{1,c}}{x_i} \le 0 \;\;\forall\;\; c \in \{B, C, D, \ldots\}. \tag{32}$$

Since we consider a situation where firm 1 produces at location A and firm 2 at location B before the home governments consider to raise taxes, the inequality in (32) holds for all c. The margin for a tax increase is given by the smallest decline in profit to all regions. Let F be the region where the decline in profit is smallest, i.e. the likelihood for relocation is highest. The objective of government A is now:

$$\max_{t_A}\; w_A = p(x_1 + x_2) - x_1 \cdot c(q_{L_A}, q_{E_A} + t_A) + t_A \cdot E_1 + t_L \cdot q_{L_A} \cdot L_1 - DA_A(E_1)$$

subject to

$$\frac{d\,\pi^1}{d\,D_F^1} = \frac{p'}{c^1}\,\frac{d\,x_2}{d\,D_F^1} - s_{L,1}\,\frac{d\,\ln\,q_L}{d\,D_F^1} - s_{E,1}\,\frac{d\ln q_E^0}{dD_F^1} - s_{t,1} \\ \frac{d\,\ln\,t}{d\,D_F^1} - \frac{\partial\,\ln\,c}{\partial\,D_F^1} - s_{F_1,F} \le 0. \tag{33}$$

In an analogous way, let region G be the region where the decline in profit is smallest for firm 2. Therefore, D_A^2 in (17) has to be replaced by D_G^2.

We conclude that the implicit reaction functions for the tax rates do not change if the relocation restriction are not binding. If one restriction is binding, e.g., (32), then $t_A = t(t_F)$ follows. The tax rate is independent on t_B if F is not country B. Environmental policy in country F where the competitor is not located at determines the tax rate. This tax rate influences $x_i(t_A, t_B)$, but strategic tax rate $\hat{t}_B$ is not strategic any more because $\hat{t}_B$ has no impact on the environmental policy of country A.

6. Eco-dumping to attract the foreign firm

We finally depart from the assumption that governments want to maintain the market structure. Government A compares welfare in country A along the curve $a_1\,b_1\,c_1\,d_1$ in Fig. 1 with welfare of country A if no firm or if both firms stay in country A. The government may then switch from the curve $a_1\,b_1\,c_1\,d_1$ to tax rates that lie below $I_A(t_A, t_B)$ or above $I_B(t_A, t_B) = 0$. Since this may cause jumps in the best reply correspondence so that possible no equilibrium of the tax competition game may exist (see Hübner for an example), we assume that economic and environmental conditions are such that it is the best strategy for government A to attract both firms to produce in country A. If countries differ in marginal damage, the country with the low marginal damage might set a low emission tax to make it profitable for the foreign firm to relocate. The government of country A could choose a level of t_A such that

$$s_{\pi^1}\,\frac{d\,\ln\,\pi^1}{d\,D_B^1} = -\frac{4}{3}\,\frac{d\,\ln\,c^1(\cdot, D_B^1)}{d\,D_B^1} - s_{F_1} \le 0 \quad \text{as well as} \tag{34}$$

$$s_{\pi^2}\ \frac{d\ \ln \pi^2}{dD_A^2} = -\frac{4}{3}\frac{d\ln c^2(\cdot, D_A^2)}{dD_A^2} - s_{F_2} > 0, \tag{35}$$

i.e., F1 stays within the country and F2 decides to relocate, given t_B in country B. If t_A is such that both inequalities hold, the market structure is a duopol producing in A. The inequality conditions are equivalent to (14) and (17) with the inequality sign, given in (35). If these inequality conditions are satisfied, both firms produce in A and the welfare maximizing problem of its government is:

$$\begin{aligned}\max_{t_A}\ w_A = {} & p[x_1(\cdot) + x_2(\cdot)]\ [x_1(\cdot) + x_2(\cdot)] \\ & - x_1(\cdot)\cdot c^1\left(\cdot D_B^1 = 0\right) - x_2(\cdot)\cdot c^2\left(\cdot D_A^2 = 1\right) \\ & + t_A \cdot [E_1(\cdot) + E_2(\cdot)] + t_L\ q_{L_A}[L_1(\cdot) + L_2(\cdot)] - DA_A(E_1(\cdot) + E_2(\cdot))\end{aligned}$$

where $(\cdot) = \left(D_B^1 = 0, D_A^2 = 1\right)$. Under the assumption of a joint production process, we get a symmetric duopol in country A:

$$\max_{t_A}\ w_A = 2(p[2x_1(t_A)]\cdot x_1(t_A) - x_1\ c(\cdot) + t_A \cdot E_1 + t_L \cdot q_{L_A}\cdot L_1) - DA_A\ (2E_1) \tag{36}$$

subject to (34) and (35). The Lagrange function for the Kuhn-Tucker conditions is:

$$\begin{aligned}L(t_A, \lambda, \mu) = {} & 2(\pi_1(x_1(t_A), t_A) + t_A \cdot E_1 + t_L \cdot q_{L_A}\cdot L_1) \\ & - DA_A(2E_1) + \lambda[(28)] - \mu[(29)].\end{aligned}$$

The condition for an optimal tax t_A, given t_B in (34) and (35), is:

$$\begin{aligned}L_{t_A} = {} & 2\cdot t_A\ \frac{\partial E_1}{\partial t_A} + 2t_L\cdot q_{L_A}\ \frac{\partial L_1}{\partial t_A} - MDA_A\cdot\left(2\cdot\frac{\partial E_1}{\partial t_A}\right) \\ & + \lambda\frac{\partial}{\partial t_A}[(34)] - \mu\frac{\partial}{\partial t_A}[(35)] \le 0\end{aligned} \tag{37}$$

$$L_\lambda = [(34)] \le 0 \tag{38}$$

$$L_\mu = -[(35)] \le 0 \tag{39}$$

and

$$t_A\cdot L_{t_A} = 0\,, \qquad \lambda\cdot L_\lambda = 0\,, \qquad \mu\cdot L_\mu = 0. \tag{40}$$

There are four possible solutions:

The case $\lambda = 0,\ \mu = 0$ implies that marginal damage is (seen to be) low in A. The tax t_A is low and both firms will produce in A, given t_B. The tax follows from (37), i.e., MDA is adjusted downwards by the job creation aspect:

$$\hat{t}_A = MDA_A - \frac{t_L\cdot q_{L_A}\ \frac{\partial L_1}{\partial t_A}}{\frac{\partial E_1}{\partial t_A}} \tag{41}$$

If we had dropped this aspect, $\hat{t}_A$ would have been a first best Pigou tax. The intuition is that the tax corrects the environmental externality, and other externalities like relocation of domestic firms or attracting foreign firms require no additional policy aspect. Since both firms produce in one country, there is no need for additional eco-dumping in order to gain market shares on a third market.[18]

In case of $\lambda \neq 0$, $\mu = 0$, marginal damage is high in A and so is $\hat{t}_A$. The tax follows from (24) which is equivalent to (34) as equation and makes F1 indifferent with respect to its location decision. F2 considers $\hat{t}_A$ as low compared to t_B and relocates. This case implies that the $I_C(t_A, t_B) = 0$ curves must intersect in the (t_A, t_B)-space.

If $\lambda = 0$, $\mu \neq 0$, F1 considers $\hat{t}_A$ as low and will not migrate. If $\hat{t}_A$ is compared to t_B, however, F2 has to be attracted by a lower tax than $\hat{t}_A$ which follows from (35) as indifference condition, i.e., from its equivalent condition (25).[19]

Finally, if $\lambda \neq 0$, $\mu \neq 0$, $\hat{t}_A$ has to solve simultaneously (34) and (35) as equalities. Environmental damage matters in A but not so much in B. The upper limit for t_A is to achieve indifference for the domestic firm ($\hat{t}_A$ from (34), i.e. from (24)), and disregard the idea to attract the foreign firm.

It is obvious that a tax competition between the two governments to attract both firms would imply the indifferent solution for both firms, i.e. $\hat{t}_A$ and $\hat{t}_B$ have to solve (34) and (35) as equalities. This outcome implies that each firm stays in its home country.

5. Summary and conclusion

Whether a firm wishes to relocate or to invest abroad depends, among other things, on the framework which is provided by the government.[20] To a certain extent, governments are able to keep mobile factors of production at home if those factors can be attracted from abroad. The purpose of this paper has been to outline an analytical framework which captures the full scope of locational competition. Cost differences, one of the reason for migration of firms, result from differences in factor prices, including differences in the tax system (e.g., capital or non-wage labor cost), in human capital, in R&D expenditure, in infrastructure services, in public goods and, finally, in total factor productivity. If cost differences are small, locational competition controls excessive government power. In that case, a country with strict regulation and high tax rates will suffer from its politics. We have modeled locational competition by assuming that governments have a vital interest to keep mobile factors of production at home. We represent this aspect by restricting the level of the environmental instrument such that it will exhaust at the utmost the cost difference to a competing country. If cost differences are significant, then threats to relocate are not credible, i.e. there is no binding restriction for the cost-benefit calculus of a national environmental policy. In that case the government will tax according to marginal damage, but adjusts this tax rate downwards to shift profit from the foreign to its domestic firm in

[18] Note that there is no tax game between the governments because the government of B is passive and sticks to t_B. The tax in (41) does not depend on t_B. Therefore (41) is not the reaction function, depicted in Fig. 1, but a vertical line with t_B beyond $I_B(t_A, t_B) = 0$.

[19] Since indifference is not enough to attract F2 if it has already set up a plant in B, has to be somewhat below the indifference level.

[20] See Siebert (1999) for aspects on locational competition.

addition to maintaining labor income of its residents under the lower economic activity. If small cost differences do not allow taxation according to marginal damage, then locational competition restricts the scope of action of the government and a relocation indifference restriction is used to exhaust the possibility of at least a small environmental tax. Our approach to locational competition was based on the consideration that governments are not interested in inducing mobile factors to leave the country. By this assumption we circumvented the fact that physical capital is completely mobile ex ante when capital is not yet embodied in machinery, but it is almost immobile ex post. Our plan for future research is to model mobility of new capital, i.e. investment, while running the domestic plant without reinvesting in machinery. This aspect implies increasing returns to scale of the new, but small, foreign plant and requires a more complex analysis. However, before one starts with such an approach, empirical investigations should indicate that firms really set up plants in foreign countries because of a strict environmental regulation at home.

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