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Environmental Policies in Open Economies and Leakage Problems*

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1 Introduction

Environmentalists and sector-specific interest groups often demand that environmental policies in open economies be accompanied by trade policies that eliminate the cost advantages that producers enjoy in less regulated countries. Several arguments have been used to support this idea. Industry interest groups often claim that firms producing in low-regulation countries are given an unfair advantage in international competition and that, therefore, some kind of countervailing duty is needed to re-establish fair competition. Some environmentalists use similar arguments when they say that foreign environmental standards are too lax and that domestic policies should be used to save foreign countries, particularly developing ones, from becoming pollution havens. To the trade economist (and probably to the environmental economist, too) these arguments are hardly convincing. A country's environmental policy should be determined by its endowment with environmental resources. This depends on physical and geographical conditions but also on the willingness of its people to pay for environmental quality. Since countries differ in these respects, environmental policies should differ as well, and it does not make sense to introduce policy measures that level the playing-field. There is, however, still another argument in favour of trade intervention. This is the leakage problem. Tighter environmental policies in one country may lead to higher emissions in other countries, and in the case of transfrontier pollution spillovers, the regulating country suffers from these emissions as well. It turns out that trade interventions can be justified as unilateral second-best policy measures if a cooperative solution to the transfrontier pollution problem is not

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available. This paper is an attempt to re-assess the leakage problem, to give some rough quantitative estimates of its magnitude and to compare its relevance in situations with perfect competition versus oligopolistic markets.

There are three channels through which leakage problems are generated. The first one is trade in final goods. If domestic environmental regulation becomes stricter, then the domestic production of environmentally intensive goods becomes relatively more expensive and the comparative advantage in this production is shifted abroad. Emissions in the rest of the world tend to increase and this creates leakage problems. The second channel is factor movements. If a country tightens its environmental standards, this reduces the productivity of the other factors of production. If they are internationally mobile, they will emigrate and move to countries with less stringent environmental policies. If they are employed there, additional demand for the use of environmental resources in production is generated and emissions in crease. In the recent debate, this relocation of factors has been termed 'environmental capital flight'. The third channel is trade in primary goods or factors of production. This is particularly important in the case of energy resources. If a country implements a tax on greenhouse gases, then its energy demand tends to be reduced. This leads to reduction in world energy prices and to an increase in demand in the rest of the world. Thus, greenhouse gas emissions are increased there and the domestic policy is (at least partially) eroded. In the present paper, I deal with the second and third channels only. Trade in final goods is not considered. Of course, this is a limitation of the model, albeit probably a less severe one than one might think at a first glance. Factor movements and trade in final goods are substitutes in the model setting I use and, thus, not much would be added by complicating the model by the introduction of trade in final commodities.[1]

Probably, the first paper that established optimal tariffs as an instrument to deal with transfrontier pollution problems is that by *Markusen* (1975). For a generalisation see *Rauscher* (1997, ch.5). Leakage in the context of international factor movements has been considered by *Rauscher* (1997, ch. 3).

Computable general-equilibrium models have been analysed by *Oliveira-Martins/Burniaux/Martin* (1993), *Felder/Rutherford* (1993), *Manne/Oliveira-Martins* (1994), and *OECD* (1995). It turns out that the results are highly sensitive to the parameters used in the models, e.g. energy demand elasticities and the future integration of China with its huge coal reserves into the world economy. Carbon leakage figures derived from these models range from merely three to forty percent of original emission reductions. It should noted that these models do not consider the possibility of international factor movements, that may accelerate carbon-leakage. International factor movements are taken into account by *Ulph* (1994) in a non-competitive partial-equilibrium model. He calibrates it for the fertilizer industry and he finds even higher leakage figures of more than sixty

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1 See *Markusen* (1983) for situations in which trade and factor movements are not substitutes but complements.

percent. The overall impression from this literature is that the empirical results are still a rather mixed bag and do not provide a reliable guideline for estimating the practical relevance of pollution leakage.

The present paper will use a simple model to re-consider the leakage problem. Realistic parameter values will be inserted to calibrate the model and to do some sensitivity analyses. The paper is organised as follows. The next section will be used to present the basic model. Section 3 looks at the leakage problem, i.e. the effect of a reduction in domestic emissions on foreign emissions. Section 4 is concerned with noncompetitive markets in a strategic-environmental-policy framework. Capital movements will be considered in Section 6. The final part of the paper summarises the results.

2 The Model

Consider a world consisting of two countries, the home country and the rest of the world. All variables and parameters of the home country are represented by lower-case letters and the variables and parameters of the rest of the world by the corresponding upper-case letters. There are two variable factors of production, capital and energy, k and e, which are employed in a production process described by a well-behaved neoclassical production function:

(1) $f(k,e)$,

(1') $F(K,E)$

There may be other factors of production such as land and labour by they are taken as given here. For the calibration of the model, we assume a CES (constant-elasticity-of substitution) technology auch that

(2) $$f(k,e) = \left(ak^{\rho} + be^{\rho} + c\right)^{1/\rho},$$

(2') $$F(K,E) = \left(aK^{\rho} + bE^{\rho} + C\right)^{1/\rho},$$

where c and C represent the impact of factors of production not considered explicitly here. The elasticity of substitution is $1/(\rho - 1)$. Moreover, $\rho<1$ and $a+b<1$.

The calibration of the model is based on some stylised facts. In most countries, the GDP shares of capital income and expenditure for primary energy are roughly 0.3 and 0.1, respectively. Moreover, the price elasticity of energy demand is less than unity. Perfect competition implies that marginal productivities equal factor prices. For the case of a CES production function, we have

(3a) $$\frac{f_k k}{f} = \frac{ak^{\rho}}{ak^{\rho} + be^{\rho} + c} = 0.3,$$

(3b) $$\frac{f_e e}{f} = \frac{be^{\rho}}{ak^{\rho} + be^{\rho} + c} = 0.1,$$

(3c) $$\eta = \frac{f_e}{ef_{ee}} = \frac{1}{(\rho - 1)\left(1 - \frac{be^{\rho}}{ak^{\rho} + be^{\rho} + c}\right)} = \frac{1}{0.9(\rho - 1)}.$$

Arguments of the production function have been omitted for convenience and subscripts denote partial derivatives. From (3b), we have that ρ should be negative, i.e. the production function should be inelastic. For ρ =-1, the price elasticity is -0.56; for ρ=-3, it is -0.28. Probably, the latter value is more realistic.

There are international capital movements. The countries are endowed with capital stocks $k^0$and K^0, respectively. Capital is fully employed:

(4) $$k^0 + K^0 = k + K.$$

Under the assumption of perfect capital mobility and perfect competition, the allocation of capital is determined by

(5) $$f_k + \sigma = F_K + \Sigma$$

where the subscripts denote partial derivatives and σ and Σ are subsidies on capital.

Energy is produced in the home and the foreign countries. Both countries use a part of their GDP to provide energy resources. These costs are $g(e^s)$ and $G(E^s)$ where, e^s and E^s denote domestic and foreign energy supply. We have

(6) $$g'(e^s) = P + \theta,$$

(6') $$G'(E^s) = P + \Theta,$$

where the world market price is P and θ and Θ are import taxes (export subsidies). Inversion of these functions gives the energy supply functions, $e^s = s(P+\theta)$ and $E^s = S(P+\Theta)$.

The world energy market is in equilibrium if

(7) $$s(P+\theta) + S(P+\Theta) = e + E.$$

Energy use is taxed at rates t and T, such that energy demand is determined by

(8) $$f_e = P + \theta + t,$$

(8') $$F_E = P + \Theta + T.$$

Energy use creates global environmental problems such as the greenhouse effect or ozone depletion. Envrionmental externalities are independent of the location of the source of emissions and environmental damages are evaluated with damage functions $d(e+E)$ and $D(e+E)$ that have positive and non-decreasing partial derivatives.

National welfare is

(9) $$w = f(k,e) - g\big(s(P+\theta)\big) + (s(P+\theta) - e)P + (k^0 - k)(f_k + \sigma) - d(e+E),$$

(9') $$W = F(K,E) - G\big(S(P+\Theta)\big) + (S(P+\Theta) - E)P + (K^0 - K)(F_K + \Sigma) - D(e+E).$$

Its components are output, energy supply costs, income from energy exports, rent income from capital invested abroad, and environmental damage. Of course some income welfare components can be negative if the country under consideration is an importer of energy or of capital services. This concludes the exposition of the model.

3 The Leakage Problem

Assume the home country wishes to use a stricter environmental policy, e.g. by raising the energy tax. This has the following adverse effects on the domestic environment. On the one hand, an increase in domestic energy prices reduces domestic energy demand. If the home country is large, this has a significant effect on global energy demand and world market prices decline. Thus, energy demand is going to rise in the rest of the world. On the other hand, domestic capital productivity is reduced when energy prices rise and capital will move abroad. This raises the productivity of the other factors of production in the rest of the world, and energy demand will rise there.

The effects of a change in domestic energy use on foreign energy use is determined by total differentiation of:

(5) $$f_k + \sigma = F_K + \Sigma,$$

(7) $$s(P+\theta) + S(P+\Theta) = e + E.,$$

(8') $$F_E = P + \Theta + T.$$

Assume that foreign energy taxes and import duties are given. Then, the comparative statics are

(10) $$\begin{pmatrix} F_{KK} + f_{kk} & F_{KE} & 0 \\ F_{KE} & F_{EE} & -1 \\ 0 & 1 & -s' - S' \end{pmatrix} \begin{pmatrix} dK \\ dE \\ dP \end{pmatrix} = \begin{pmatrix} f_{ke} & 1 & 0 \\ 0 & 0 & 0 \\ -1 & 0 & s' \end{pmatrix} \begin{pmatrix} de \\ d\sigma \\ d\theta \end{pmatrix}$$

and the leakage effect is

$$\text{(11)} \qquad \frac{dE}{de} = \frac{(s'+S')\, f_{ke} F_{KE} - f_{kk} - F_{kk}}{-(s'+S')\left(\left(f_{kk} + F_{KK}\right)F_{EE} - F_{KE}^2\right) + f_{kk} + F_{KK}} \quad < \quad 0.$$

This can be rewritten if we express (s'+S') in terms of elasticities. It is assumed here that there are no trade interventions and restrictions on capital mobility:

$$s'+S' = \frac{(s'+S')P}{e+E}\frac{e+E}{E}\frac{P+T}{P}\frac{F_{EE}E}{P+T}\frac{1}{F_{EE}} = \frac{\varepsilon}{\eta}\frac{e+E}{E}\frac{P+T}{P}\frac{1}{F_{EE}} \equiv \frac{\xi}{F_{EE}}$$

where ε and η are the price elasticities of world energy supply and foreign energy demand, respectively. The parameter ξ is introduced for notational convenience. This is can now be used in equation (11).

$$\text{(12)} \qquad \frac{dE}{de} = \frac{\xi\, f_{ke} F_{KE} - \left(f_{kk} + F_{KK}\right)F_{EE}}{-\xi\left(\left(f_{kk} + F_{KK}\right)F_{EE} - F_{KE}^2\right) + \left(f_{kk} + F_{KK}\right)F_{EE}} \quad .$$

To obtain some quantitative results, assume that both countries differ only in size:

$$\frac{k}{K} = \frac{e}{E} = \frac{f(k,e)}{F(K,E)} = ß.$$

Then we have

$$\text{(12')} \qquad \frac{dE}{de} = -\frac{ß\xi - (1+ß)\left(1 - \frac{F}{KF_K}\right)\left(1 - \frac{F}{EF_E}\right)}{(1+ß)(\xi - 1)\left(1 - \frac{F}{KF_K}\right)\left(1 - \frac{F}{EF_E}\right) - \xi}.$$ [2]

Using assumptions (3a) and (3b), we arrive at

$$\text{(12")} \qquad \frac{dE}{de} = -\frac{ß\xi - 21(1+ß)}{21(1+ß)(\xi - 1) - \xi}.$$

This can be calibrated easiliy with realistic values of the elasticities, the relative country sizes and the levels of energy taxation abroad. It is assumed that ε/η takes values between -0.5 and -2 and that foreign energy tax rates are 0, P, and 2P. Moreover, we look at cases were countries accounting for 20 or 50 per cent of world energy demand reduce their energy input, i.e. $ß$ equals 0.25 or 1. See Table 1. There is quite some variety in the leakage results. The most realistic parameter combinations produce leakage effects in the range of 15 to 35 per cent.

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2 Note that this is independent of the elasticity of substitution.

Thus, these simple back-of-the-envelope calculations reproduce the leakage effects that have been obtained from computable general-equilibrium models such as *Oliveira-Martins/Burniaux/Martin* (1993), *Felder/Rutherford* (1993), *Manne/Oliveira-Martins* (1994), and *OECD* (1995). The disadvantage of my one-sector model of course is the simplistic approach to calibration It neglects the complexity of inter-sectoral interdependencies of the economy and the existence of barriers to trade and factor movements. The advantage is that the effects of parameter changes are very obvious and intuitive.

ε/η	T	$\frac{dE}{de}\ (ß = 0.25)$	$\frac{dE}{de}\ (ß = 1)$
-0.5	0	-0.628	-0.518
-1.0	0	-0.459	-0.355
-2.0	0	-0.301	-0.223
-0.5	P	-0.459	-0.355
-1.0	P	-0.301	-0.223
-2.0	P	-0.180	-0.135
-0.5	$2P$	-0.363	-0.273
-1.0	$2P$	-0.225	-0.167
-2.0	$2P$	-0.130	-0.101

Table 1: Leakage in a Competitive Markets Framework

In order to get a better intuition for the results and to interpret them economically, I will separate the two sources of leakage. Scenario A will consider energy-market effects only whereas scenario B will be restricted to the effects of international capital movements..

Scenario A. Capital mobility is restricted and leakage effects are due to the decline in world energy prices only. Then we have:

(11A) $$\frac{dE}{de} = -\frac{1}{1-(s'+S')F_{EE}}$$

Two things are remarkable here. First, the leakage effect is bound from below by -1. Thus it is not possible that a reduction in domestic emissions by one unit is accompanied by a more-than-one-unit increase in foreign emissions. Moreover, leakage is the more significant the less elastic energy supply is. The explanation for this is straightforward. With inelastic supply, a reduction in domestic energy use has a strong price effect. This in turn implies that foreign energy demand increases substantially. As has been done in the general case, equation (11A) can be rewritten in terms of elasticities if we assume that there are no trade taxes in the initial situation: Then, we have

(12A) $$\frac{dE}{de}=-\frac{1}{1-\frac{\varepsilon}{\eta}\frac{P+T}{P}\Big/\frac{E}{e+E}}$$

or

(12A') $$\frac{dE}{de}=-\frac{1}{1-\xi}$$

Besides the impact of the elasticity of supply, additional effects can be identified.

- Leakage is the more important, the larger the price elasticity of foreign demand energy is.
- If the rest of the world uses high energy taxes, the leakage effect is small. For in the case of high energy taxes, the relative price change compared to the initial situation is small.
- If the rest of the world is large compared to the home country, the leakage effect is substantial. Interestingly, the leakage effect turns up even if the home country is very small (*e* close to 0). If world energy demand is reduced by one unit, this has a price effect even if this unit is due to an change in Luxembourg's environmental policy.

In order to assess the magnitude of leakage, I use the same parameter values as before. The results are contained in table 2 and it is seen that the leakage effetcs are differ only slightly from the ones derved from the original model. One may conclude that energy-market interdependencies are the most important source of leakage. However, since the effects of energy-market interdependencies and capital movements are linked in a non-trivial way in this model (see equation (11)), this conjecture requires a bit of additional investigation. Therefore, we will now consider the leakeage effects of international capital movements.

ε/η	T	$\frac{dE}{de}$ $(ß=0.25)$	$\frac{dE}{de}$ $(ß=1)$
-0.5	0	-0.614	-0.500
-1.0	0	-0.444	-0.333
-2.0	0	-0.286	-0.200
-0.5	P	-0.444	-0.333
-1.0	P	-0.286	-0.200
-2.0	P	-0.167	-0.111
-0.5	$2P$	-0.348	-0.250
-1.0	$2P$	-0.211	-0.143
-2.0	$2P$	-0.118	-0.077

Table 2: Energy Markets and Leakage in the Competitive Model

Scenario B. There is no trade in energy. All leakage effects are due to environmental capital flight. The leakage effect in this case is:

(11B) $$\frac{dE}{de} = -\frac{f_{ke} F_{KE}}{(f_{kk} + F_{KK}) F_{EE} - F_{KE}^2}.$$

To obtain quantitative results, assume again that both countries differ only in size. The size of the home country is *ß* times that of the rest of the world. In the case of a CES production function, the leakage effect turns out to be

(12B) $$\frac{dE}{de} = -\frac{ß}{(1+ß)\left(1-\frac{F}{KF_K}\right)\left(1-\frac{F}{EF_E}\right)-1}.$$

Using the assumptions (3a) and (3b), we get *dE/de* = - *ß/*(21(1+*ß*)-1). Thus, the leakage effect must be less than 1/21. If *ß* equals 0.25 or 1, i.e. if the countries restricting their environmental policies own one fifth or half or of the world capital stock, leakage effects are 1/31 or 1/101, respectively. These rather small values indicate that the major part of the leakage problem is indeed due to energy-market interdependencies but not to environmental capital flight. It should be noted that international factor movements and foreign trade are substitutes in a world of perfect competition. This means that even if we considered trade in final commodities, leakage effects should not be expected to be larger than in this simple model.

Result 1

In the case of perfectly competitive markets, leakage effects are to be expected in the range of 15 to 35 percent. The major part (some 90 per cent) of this is explained by the effects of energy taxes on world energy pricess. The impact of environmental capital flight is almost negligible.

Finally the question arises as to whether leakage effects are stronger if there are two sources of leakage than if there is only one source. The appendix shows that this is not generally the case that the counter-intuitive result is possible for unrealistic parameter constellations only.

4 Optimal Environmental and Trade Policies

In the process of determining its environmental policy, a country should take leakage effects into account. In a first step, assume that only one policy instrument is used. This is an emission tax or a tradable-permits scheme. The optimal environmental policy is determined by deriving the welfare functional, equation (9), with respect to domestic emissions. This yields

$$t+\theta = f_e - P = \left(1+\frac{dE}{de}\right)d' - f_{ke}(k^0-k) + \left((k^0-k)f_{kk} - \sigma\right)\frac{dK}{de} - (s-e-s'\theta)\frac{dP}{de} \tag{13}$$

It follows from equation (10) that

$$\frac{dK}{de} = \frac{-(s'+S')f_{ke}F_{EE} + F_{KE}}{-(s'+S')\left(\left(f_{kk}+F_{KK}\right)F_{EE} - F_{KE}^2\right) + f_{kk} + F_{KK}} < 0 \tag{14}$$

and

$$\frac{dP}{de} = \frac{f_{ke}F_{KE} - \left(\left(f_{kk}+F_{KK}\right)F_{EE} - F_{KE}^2\right)}{-(s'+S')\left(\left(f_{kk}+F_{KK}\right)F_{EE} - F_{KE}^2\right) + f_{kk} + F_{KK}} < 0. \tag{15}$$

If no other policy instruments are used (σ=0, θ=0), then there are three effects that are responsible for the deviation of the energy tax from the Pigouvian tax rate, d'. The first one is carbon leakage. Leakage effects result in low environmental tax rates. If there is 20 per cent leakage, the tax should be only 80 per cent of the domestic marginal damage. The next effect is a rate-of-return effect. See also *Rauscher* (1997, ch. 3). Environmental regulation affects the world interest rate, and a large country should take this into account. Tight regulation reduces the marginal productivity of capital and is, therefore, good for the country that is a capital importer. By the same argument, the capital-exporting country should be interested in high rates of return and, thus, choose a lax environmental policy. The last term is a terms-of-trade effect. An energy-exporting country should increase its domestic energy demand in order to keep world market prices high. An energy-importing country should tax energy at high rates because this reduces the world market price.

Additional effects have to be considered if other market interventions such as tariffs and taxes or subsidies on capital are used. Then, the optimal environmental tax is used to correct the distortions generated by the use of other policy instruments. For instance, if capital is taxed (σ < 0), then a fiscal externality is to be considered. The countries compete for a mobile tax base and the appropriate measure is to reduce environmental taxes since this raises the marginal productivity of capital and attracts investors.

In order to concentrate on the leakage effect, assume that the countries under consideration are identical. Then the rate-of-return and terms-of-trade effects vanish. And we have

(16a) $$t = f_e(k,e) - P(2e) = \left(1 + \frac{dE}{de}\right) d'(2e)$$

whereas the optimal tax rate (indicated by an asterisk) is

(16b) $$t^* = f_e(k,e^*) - P(2e^*) = 2d'(2e^*)$$

where e^* is the corresponding emission level. World market prices of course depend on the level of energy demand. Optimal and non-cooperative taxes are depicted in Figure 1. The negatively sloped line is the marginal-productivity locus

Given that there are three effects and only one policy instrument, it is obvious that this policy is not first best. It would be better to use additional policy instruments such as tariffs and capital taxes or subsidies. In this case, the first-order conditions are

(17) $$\begin{pmatrix} \frac{dK}{de} & \frac{dP}{de} & \frac{dE}{de} \\ \frac{dK}{d\sigma} & \frac{dP}{d\sigma} & \frac{dE}{d\sigma} \\ \frac{dK}{d\theta} & \frac{dP}{d\theta} & \frac{dE}{d\theta} \end{pmatrix} \begin{pmatrix} (k^0 - k) f_{kk} - \sigma \\ -(s - e + s'\theta) \\ -d' \end{pmatrix} = \begin{pmatrix} f_e - P - d' + (k^0 - k) f_{ke} \\ k^0 - k \\ -s'\theta \end{pmatrix}.$$

From equation (10), we have that

(18) $$\begin{pmatrix} \frac{dK}{de} & \frac{dP}{de} & \frac{dE}{de} \end{pmatrix} = \begin{pmatrix} f_{ke} & -\frac{1}{s'} \end{pmatrix} \begin{pmatrix} \frac{dK}{d\sigma} & \frac{dP}{d\sigma} & \frac{dE}{d\sigma} \\ \frac{dK}{d\theta} & \frac{dP}{d\theta} & \frac{dE}{d\theta} \end{pmatrix}$$

and this implies that the emission tax rate to be chosen in this case equals the Pigouvian tax rate, i.e.

(19a) $$t = f_e - P - \theta = d'.$$

Equations (10) and (17) can then be used to determine the optimum tariff and the optimum capital subsidy or tax. Since I wish to concentrate on the leakage effect (and also to make matters simpler), it is assumed that the two economies are identical such that there are neither trade nor capital movements. Then, the terms-of-trade and rate-of-return effects vanish and we have

$$\sigma \frac{dK}{d\sigma} + s'\theta \frac{dP}{d\sigma} + d' \frac{dE}{d\sigma} = 0 ,$$

$$\sigma \frac{dK}{d\theta} + s'\theta \frac{dP}{d\theta} + d' \frac{dE}{d\theta} = s'\theta ,$$

and we can use the comparative-statics results, eq. (10) to obtain

and it follows that

(21) $$\sigma = -d' \frac{F_{KE}}{F_{EE}}$$

and

(22)

remains to be completed

5. Leakage Problems in a Strategic-Trade-Policy Framework

We now move to a non-cooperative model. The setup is that of the strategic trade policy model of *Brander/Spencer* (1985). See *Barrett* (1994) and *Rauscher* (1997) for applications to environmental policies. Consider a situation where a domestic and a foreign firm compete in a third country's market.[3] It is assumed, that due to the partial-equilibrium character of this model, the prices of energy and capital are given to the from the point of view of the firms. They play Nash-Cournot against each other and the governments play Stackelberg vis-à-vis the firms and Nash against each other. Profits of the firms are:

(22) $$\pi = P(q+Q)q - c(q, P+t, r-\sigma) ,$$

(22') $$\Pi = P(q+Q)Q - C(Q, P+T, r-\Sigma) ,$$

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3 The third-country assumption simplifies the analysis considerably. It implies that a subsidy on production and a subsidy on exports are equivalent and that the consumer surplus does not have to be considered in the welfare analysis.

where $c(.,.,.)$ and $C(.,.,.)$ are cost functions and r is the rental rate of capital.

The first-order conditions for an optimum are

(23) $$P'q + P - c_q = 0,$$

(23') $$P'Q + P - C_Q = 0.$$

It is assumed that the second-order conditions are satisfied, i.e. $\pi_{qq}<0$ and $\Pi_{QQ}<0$. The comparative-static results are obtained by application of Cramer's rule to

(24) $$\begin{pmatrix} P''q + 2P' - c_{qq} & P''q + P' \\ P''Q + P' & P''Q + 2P' - C_{QQ} \end{pmatrix} \begin{pmatrix} dq \\ dQ \end{pmatrix} = \begin{pmatrix} c_t\, dt \\ C_T\, dT \end{pmatrix}.$$ [4]

The slopes of the reaction functions, $q = r(Q,t)$ and $Q = R(q,T)$ are

(25) $$\frac{\partial r}{\partial Q} = -\frac{P''q + P'}{P''q + 2P' - c_{qq}} < 0,$$

(25') $$\frac{\partial R}{\partial q} = -\frac{P''Q + P'}{P''Q + 2P' - C_{QQ}} < 0,$$

and that the domestic firm's reaction curve is steeper than the foreign firm's curve. See figure 1. The Nash equilibrium, *N*, is the point of intersection of the reaction curves denoted by *r* and *R* in the diagram. It is assumed to exist and to be unique. Moreover, the domestic and foreign firm's iso-profit curves are depicted in this diagram. Each firm would benefit if the other firm reduced its output. The shaded area represents the potential of profit increases that can be achieved by cooperation, i.e. by a cartel agreement. The reaction functions have been derived for given environmental tax rates. If the domestic tax rate is reduced, the domestic firm's reaction function is shifted outwards. This is depicted by the dashed line. If the domestic firm were the Stackelberg leader, it could attain point *S* where it maximises its profits for a given reaction function of the foreign firm. In the *Brander/Spencer* (1985) model, this situation is achieved by government intervention.

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4 See *Dixit* (1986) for a general treatment of comparative statics of the Cournot equilibrium.

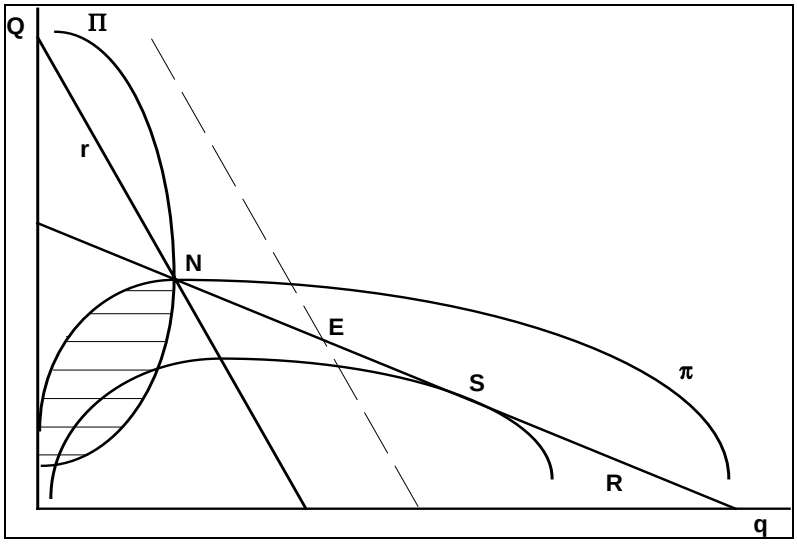

Figure 6.5: Strategic Environmental Policy in the Cournot Model

Before we look at optimal government interventions, let us consider the effect of a tightening of domestic environmental policy on domestic emissions. Emissions can be obtained in this model from Shephard's lemma:

(26) $e = c_t$

(26') $E = C_T$.

Let us now look at optimal environmental policies. Consider first, as a reference case, a situation in which the government does not behave strategically. Then the optimal tax rate is the marginal social cost, i.e. $t = d'$. Correspondingly, $T = D'$ for the foreign country. Let us assume that the reaction functions that are represented by solid lines in figure 6.5 are based on this type of government behaviour.

Let us now introduce strategic behaviour. The home government's objective function is

(28) $\pi - d(c_t + C_T) + tc_t$

Differerentiation with respect to t and the use of the firm's first-order condition, π_q=0, yield the optimal tax rate

(29) $t = d' - \dfrac{p_Q q - d' C_{QT}}{c_{tt} + c_{tq} q_t} Q_t$.

(29'') $$T = D' - \frac{P_q Q - D' c_{qt}}{C_{TT} + C_{TQ} Q_T} q_T$$

is the optimal tax rate in the foreign country. The derivatives of the outputs, q and Q, with respect to the tax rates, t and T, can be obtained by the application of Cramer's rule to equation (24). It follows that q_T and Q_t are positive. Together with the signs of the other terms this implies that the second terms on the right-hand sides of equations (29) and (29') are positive. It is to be concluded that, if the government uses environmental policy strategically, it should not completely internalize the environmental cost of production.

The second term on the right-hand side of equation (29) represents the incentive for using environmental policy strategically. There are two effects. First, if the government reduces the tax rate towards a level below the marginal damage, the domestic firm produces more and this leads to an increase in profits that exceeds the welfare loss due to increased environmental deterioration (provided that the tax rate is not reduced by too much). Second, low domestic emission taxes force the foreign firm to reduce its output and this reduces transfrontier pollution.[5]

6 Strategic Considerations and Relocation

Up to now we have assumed that the non-competitive firm is an established enterprise in the home or the foreign country. We will now look at the locational decision. In which country will a polluting plant be raised and which consequences does this have for environmental policies. Here, indivisibilities will be important, i.e. a certain minimum size of an investment is required; otherwise no investment will be undertaken at all. Finally, there will be trade in final goods. Models of this type have been considered by *Hoel* (1994) and *Rauscher* (1995) and *Markusen/Morey/ Olewiler* (1995). *Markusen/Morey/Olewiler* (1995) consider a situation where there is one polluting firm which decides upon the location of its plants. High firm-specific fixed costs prevent the entry of additional firms. There are two kinds of fixed costs, that of being in the market and that of setting up a plant. The variable costs include pollution abatement and trade costs. The firm may build a plant in the home country, in the foreign country, in both of them or in neither of them, and the decision is influenced by the environmental policies in the two countries. This model turns out to be rather complex even in the case of only one firm.

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5 Arguably, the transfrontier pollution problem is in most cases more severe in non-competitive models than in competitive ones. If, for instance the demand and cost functions are linear, the slope of the foreign firm's reaction curve is -½ which means that a reduction in domestic output by one unit is accompanied by an increase in foreign output by two units. Similar effects exist in competitive model frameworks as well but they tend to be much smaller. The implication is (i) that carbon-leakage problems tend to be more severe in oligopolistic markets than in competitive ones (see *Ulph* (1994) for some results from calibrated models) and (ii) that the incentive to use lax environmental policies to avoid carbon leakage is larger.

Markusen/Morey/Olewiler (1995), therefore, use a numerical example to derive some results. *Hoel* (1994) and *Rauscher* (1995c) have tried to avoid this complexity by neglecting trade costs. The model can now be analysed by simple diagrammatic methods. In what follows, a two-country version of my original *n*-country model (*Rauscher* (1995c)) will be presented.

There are two countries, the home and the foreign country, and a single firm which supplies the world market with a consumption good. The fixed costs, $\overline{C}$, are assumed to be so high that there can be only one firm in the market. Since trade costs are negligible, the firm will open at most a single plant, and the decision where to open it depends only on the level of environmental tax rates imposed by the two countries. If emission taxes are very high, the firm will not build the plant at all since profits become negative.

It is assumed here that price discrimination is not possible, i.e. the law of one price holds. The possibility of price discrimination would not alter the qualitative results. Here it turns out to be useful again to consider demand functions $c=d(p)$ and $C=D(p)$ instead of inverse demand functions. Thus, the optimization problem of the firm is to choose its price such that

(30) $$\Pi = p\big(d(p)+D(p)\big) - C\big(d(p)+D(p), \min(t^e, T^e)\big) - \overline{C}\,.$$

The firm will always locate in the country with lax environmental policies or it decides not to enter the market if emission tax rates are too high.

The carbon-leakage effect is straightforward. If the home country is the host, it can tighten its environmental policy until the foreign country is willing to become the host. Then there will be a switch and all the pollution will come from abroad. Thus the leakage effect is

(31) $$\frac{dE}{de} = \{0, -1\}$$

In real-world situations, where locational decisions are multidimensional issues, matters may be even worse and leakage effects may be much stronger. As an example consider a case of a plant in an industrialised country. The owner enjoys the benefits of being located in a developed country but pays high emission taxes. If environmental policy is tightened even further, she may be willing to relocate to a developing country that does not offer these benefits but has much lower taxes. Thus, emissions may be increased in the new host country by more than they have been reduced in the former host country.

Let us now look at optimal environmental policies. The governments are assumed to maximize social welfare, which is the sum of consumer surplus, tax revenue, tC_t or TC_t ,and the utility derived from environmental quality. In contrast to the strategic trade policy model discussed earlier, monopoly profits are not a part of the social welfare function. This may be motivated by the assumption that the monopolist's well-being has a

negligible weight in the social-welfare function or that her profits contribute to economic welfare in a third country.

The welfare of the two countries consists of three components: consumer surplus, environmental damages, and tax revenue. The tax revenue is appropriated by the host country only, consumer surplus accrues to both countries and both of them suffer from environmental pollution.

To make matters simple, assume that the countries are identical in all respects. A government deciding whether or not to host the plant has to compare the additional benefits from being the host and the costs. Since the consumer surplus is independent of the location of the plant, the only benefit from being the host is the appropriation of the tax revenue. The environmental damage is also independent of the location of the firm. Thus, if both countries conjecture that one of them is willing to be the host, environmental damages do not matter as well. By slightly undercutting its neighbour's emission tax rate, a country can appropriate the whole tax revenue, but it also has to bear the full cost of environmental disruption. Figure 2 depicts the solution of the game.

Figure 6.4 represents the game from the view of the home country. The decisive variables are tax revenue, *tr*, and environmental damage, *ed*. Moreover, the consumer surplus, *sc*, is depicted. There are two levels of the damage function, ed^0 and ed^1.

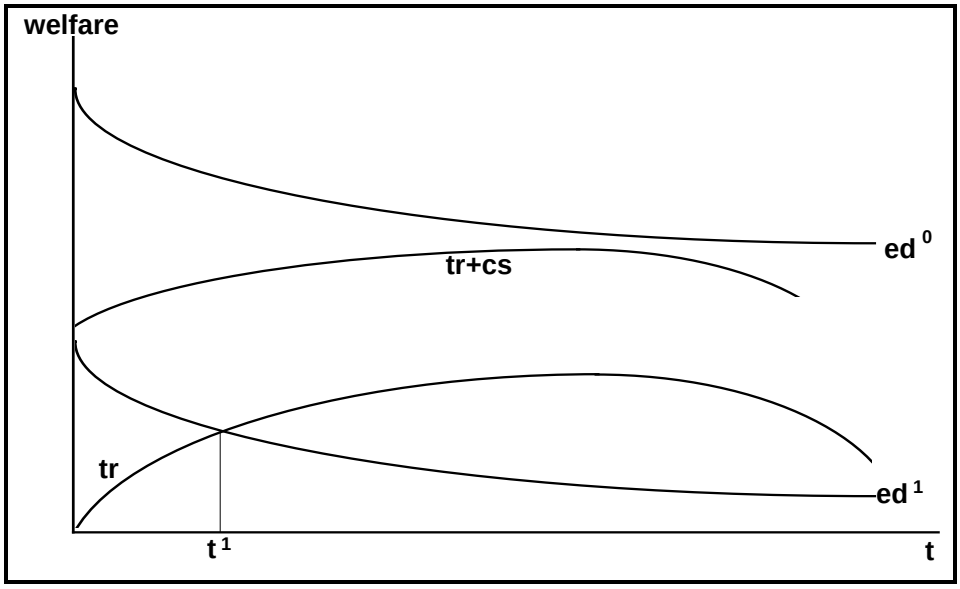

Figure 2: Interjurisdictional Competition and Locational Desicion

- If the environmental damage is very large (d^0), none of the countries benefits from being the host. Nonetheless, it may still be profitable to have the polluting firm somewhere, and this would be the outcome of

a cooperative agreement. See *Rauscher* (1995). The investment will not be undertaken because of the traditional prisoners' dilemma problem. It would be individually irrational to provide the consumer surplus to the citizens of other countries if this results in an individual welfare loss. This is the "not in my backyard" scenario of the *Markusen/Morey/Olewiler* (1995) paper.

- If the level of environmental damage is rather small, ed^1, then each of the two countries attempts to reap the net benefit by undercutting its competitor until the net benefit vanishes. If there is no transfrontier pollution, the solution is a tax rate at t^1, where the net benefit of being the host (tax revenue minus environmental damage) becomes zero. This tax rate may be much lower than the one that would be decided on in an international cooperative agreement. If transfrontier pollution is important, the opportunity costs of not being the host are increased. In the case of a global pollutant, where damages are independent of the location of the source of emissions, environmental costs become irrelevant for the tax offers of the two countries. The result is a race to the bottom in environmental taxes.

The environmental taxes discussed here are no first-best policies. Besides the internalization of the environmental externality, there are additional policy objectives that are taken care of by the emission tax, in particular the appropriation of the tax revenue. Thus, one may argue that it would be better to more than one instrument. E.g. it would be advisable to introduce subsidies in order to attract the foreign firm. This possibility will be considered initially for the simple case of identical countries and no transfrontier pollution. Let σ be a lump-sum subsidy paid by the government to the foreign firm in case the investment is undertaken. If the investment is beneficial from a single country's point of view, the two countries will compete for the foreign firm as long as the tax revenue exceeds the costs of the investment, which consist of the loss of environmental quality and the subsidy that has to be paid. The game will come to an end when this net benefit approaches zero. In order to be able to attract the firm, the home government has to choose taxes and subsidies such that the monopolist's profit is maximized - subject to the condition that

(32) $$tc_t - \sigma - d(C_t) - u(0) = 0 .$$

Differentiation of the corresponding Lagrangean function with respect to t and σ yields the optimal tax rate

(33) $$t = d'.$$ [6]

This is the Pigouvian tax, which equals the marginal environmental damage. The underlying reason is that direct subsidies are the most efficient way to attract a foreign investor. If the same subsidy were given to the firm

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6 The alternative method to compute the optimal tax rate and the subsidy is to maximize the net benefit with respect to a target level of profits. This produces the same result for the emission tax rate.

indirectly by means of low emission taxes, the increase in environmental damage would be an additional cost component which would have to be taken into account by the policy maker. Therefore, lump-sum subsidies are better means to compete for a foreign investor. The Pigouvian tax rate is, however, not the jointly optimal tax rate since it does not take account of the distortion stemming from the market imperfection.

The same result would follow if the countries were different with respect to their perception of environmental damage. In this case, the country which is more conscious of environmental quality will drop out of the rat race earlier, i.e. when the net benefit to the other country is still positive ($t^e\tilde{C}_t - \sigma + u(-sa\tilde{C}_t) - u(0) > 0$ if the home country turns is the host). Nonetheless, the two policy instruments will still be used in the most efficient way. Only the subsidy that has to be paid by the host will be lower than in the case of identical countries. Even transfrontier pollution does not change the result. The environmental-quality component of the opportunity costs of not the being host country is reduced from $u(0)$ and $U(0)$ to $u(-(1-S)AC_t)$ and $U(-(1-s)aC_t)$, respectively. But it is still independent of the government's choice of the tax rate since they are determined solely by the environmental policy in the other country. Thus, they are exogenous to the policy maker in the country under consideration and are taken as given. Then, the optimal policy is to maximize the monopolist's profits for given net benefits or vice versa and again the tax rate equals the domestic marginal environmental damage.

If lump-sum subsidies are available, there will never be a race to the bottom in the field of environmental regulation. From a welfare point of view, lump-sum subsidies are cheaper than emission-tax reductions and, therefore, they will be used to attract foreign investors. In reality, however, there may be limits to the use of lump-sum subsidies and the policy maker will search for alternative instruments. Environmental regulation is one candidate.

Summary and Conclusions

The paper has addressed environmental leakage problems in a variety of trade and factor relocation models. The following conclusions can be drawn. Leakage problems tend to be more substantial in non-competitive models than in perfectly competitive ones. The most important channel through which leakage effects are generated appears to be the markets for primary goods, in particular energy. Capital relocation appears to have less significant effects. Since the model framework used to establish this result is one where factor movements and trade are substitutes, one may (with caution) conclude that the same applies to trade in final commodities. Changes in the pattern of specialisation are likely to be much less important sources of leakage than changes in supply and demand in markets for primary goods. The existence of leakage tends to lead to too-low environmental taxes and to too-lax standards if no additional policy instruments are used. If these instruments are used, the optimal emission tax rates are the Pigouvian tax rates.

The models considered here are unrealistic in that they either assume perfectly competitive markets with atomistic actors or a given non-competitive market structure with a given number of agents. Both approaches are not particularly satisfying. There appear to be two solutions. The first one is to look at models involving a small but variable number of agents. Models of this type have been considered by *Markusen* (1996) and they rely on numerical solution techniques. The alternative is a class of models involving a larger number of firms, the market structure beng that of monopolistic competition. See *Dixit/Stiglitz* (1977) and *Krugman* (1979) for the basic models and *Rauscher* (1997, ch. 7) for an application to environmental policies in open economies. I think both classes of models deseve further inspection and promise to provide interesting insights in future research.

Appendix

In Section 3, we considered two simplified versions of the competitive model in order to isolate the effects of energy price changes and environmental capital flight. This appendix establishes conditions under which the combined effects yield stronger leakage results than the isolated single effects.

In a first step, compare the general case and scenario A, where there is no capital mobility. Assume that the hypothesis is true. Then

$$\frac{-1}{-(s'+S')F_{EE}+1} > \frac{(s'+S')f_{ke}F_{KE} - f_{kk} - F_{kk}}{-(s'+S')\left((f_{kk}+F_{KK})F_{EE} - F_{KE}^2\right) + f_{kk} + F_{KK}}.$$

This can be rearranged such that

$$F_{KE} < f_{ke}(1-(s'+S')F_{EE}).$$

Of course, this is not generally true. In order to get an intuition what one should expect for the real world, I use the assumptions on production functions and price elasticities made before. Then we have

$$ß < 1-\xi \text{ where } \xi = -(1+ß)\left|\frac{\varepsilon}{\eta}\right|\frac{P+T}{P}.$$

It follows that the counter-intuitive result is possible only if $ß > 1$ and $\left|\frac{\varepsilon}{\eta}\right|\frac{P+T}{P} < 1$. Since energy taxes are quite high in many countries and the price elasticity of energy supply is unlikely to be much larger than the price elasticity of demand, this condition is unlikely to be met in reality.

In case B, we have.

$$-\frac{f_{ke}F_{KE}}{(f_{kk}+F_{KK})F_{EE} - F_{KE}^2} > \frac{(s'+S')f_{ke}F_{KE} - f_{kk} - F_{kk}}{-(s'+S')\left((f_{kk}+F_{KK})F_{EE} - F_{KE}^2\right) + f_{kk} + F_{KK}}. \tag{15}$$

Rearranging terms yields:

$$\frac{f_{ke}F_{KE}}{(f_{kk}+F_{KK})F_{EE} - F_{KE}^2} < 1. \tag{16}$$

This is not generally true as well, but for the practically relevant parameter constellations the left-hand side of inequality (16) is less than 0.05 and, thus, this condition is likely to be met.

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