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Abstract: This paper discusses the issue of competitiveness and environmental regulation from the viewpoint of Heckscher-Ohlin models. It demonstrates that the impact of unilateral environmental regulations does not necessarily lead to a decrease in international competitiveness. Important is the measure of international competitiveness and the industry under consideration. Furthermore, this paper shows that in contrast to other theoretical work on this subject, unilateral environmental regulation does not necessarily lead to capital flight. It is also possible that the economy under consideration attracts more internationally mobile capital.

JEL-Classification: Q 20

Environmental Regulation and its Impact on Welfare and International Competitiveness in a Heckscher-Ohlin Framework

This paper is part of a research project on the effects of environmental policies on the international competitiveness. It discusses the so-called Porter Hypothesis which states that a comparably stricter environmental policy may lead to an increase in competitiveness. This paper constitutes a chapter of an intended monograph and covers the contribution of the theory of strategic environmental policies to this discussion. Other chapters on intersectoral effects in a static and dynamic strategic trade framework can be found in the Kiel Working Papers No. 858 and 859, respectively. We gratefully acknowledge financial support by the Fritz Thyssen Foundation.

1. Introduction

The fear that unilateral environmental regulation has a negative impact on international competitiveness has been a matter of public debate quite frequently. However, in order to make this discussion meaningful a definition of international competitiveness is needed, something which is usually missing in the public debate. The public debate in Germany indicates that many people think of a high trade surplus as an indicator for high international competitiveness. However, from an economic perspective this indicator does not seem to be very convincing. There is no reason to believe that welfare increases if an economy does not consume all its production, but gives part of it away. An economy produces only more than it consumes, if it has to pay debt and interest. Therefore, if an economy has a trade balance surplus this only implies that in the past the economy had a trade balance deficit. If the economy does not have neither positive nor negative debts, in equilibrium the economy will have always have equal values of export and import.

Others think that foreign direct investment is a good indicator. If the foreign direct investment in the domestic country is low or if domestic capital owners prefer to invest abroad this indicates low international competitiveness. Thus, the task of this paper is to see which impacts unilateral environmental policy has on foreign direct investment.

Another definition is used quite frequently by economists:[1] „Competitiveness [...] is defined as the degree to which a nation, under free and fair market conditions, produces goods and services that meet the test of international markets while simultaneously maintaining and expanding real incomes of its citizens." The postulate of „maintaining and expanding real incomes" implies a situation without a continued decline in the terms of trade and domestic factor prices. „Free and fair market conditions" imply that changes in the trade position of a country as a consequence of

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1 See Tyson (1988), Jaffe, Peterson, Portney, Stavins (1995). The quotation is taken from Tyson (1988), p. 97.

trade policy measures are not attributed as changes in international competitiveness. As will be shown below, situations exist in which environmental regulation might be used as trade policy. This typically takes place if the economy under consideration can influence its terms of trades. According to this definition of international competitiveness the impacts of environmental regulation must be separated into the effects that are caused by direct changes in the environmental regulation and the indirect effects that change the trade flows as a consequence of new equilibrium terms of trade.[2]

This paper analyzes the effects of a unilateral environmental regulation under perfect competition and international trade. The rest of this paper is analyzed as follows: The first section analyzes the impact of unilateral environmental regulation on welfare and on various indicators of international competitiveness under the assumption that capital internationally immobile in a small and large open economy. The next section extends the analysis to include international capital mobility also in a small open and large open economy framework. The last section concludes.

2. Environmental Regulation in a Heckscher-Ohlin Framework

The analysis of this paper neglects distortions resulting from taxation or trade barriers completely. The only distortion that is allowed results from a negative externality in production. The model is a standard two commodity Hekscher-Ohlin trade model. Two variations are considered: The first version considers a small open economy that faces exogenous terms of trade. The second version considers a large economy that can influence its terms of trade.[3] The production sector uses pollution as an input factor which creates a negative externality in the household sector which has a preference for environmental quality. Two possible ways of modeling pollution can be identified.

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2 See Jaffe, Peterson, Portney, Stavins (1995) for this opinion.

3 The small open economy version of this model follows essentially Copeland (1994).

Pollution can be a private good. In this case the economy faces an endowment constraint for the factor pollution. Efficiency arguments in the production sector usually lead to full use of pollution. In this sense pollution is usually interpreted as an indicator for the endowment of environment of the economy and the supply of the factor pollution is completely inelastic. Even if the government taxes the use of pollution this will not change the amount of pollution applied in production, because the production sector is able to shift the burden of any price change fully to the suppliers of pollution. Therefore, any tax on pollution will be completely offset by changes in the market price for pollution. The only way how the government can influence the amount of pollution used in production is to limit the supplied quantity of pollution. De facto this tantamount to reducing the endowment constraint of the economy.

The other way how one might think about pollution is to understand pollution as a public bad. Pollution is not really an input into production, but rather a joint output of production. Understood in this way the production sector produces consumption goods and a joint output pollution. The economy does not face any endowment restriction, but the level of environmental quality is determined by the joint product. How much the firms produce of the joint output pollution depends on the prices they face. The environmental policy instrument is now the emission tax. The emission tax in combination with other factor prices determines the pollution output of firms.

In this paper both ways of modeling pollution, namely the private good and the public good case, are considered. Also considered is international factor mobility. As is well known, the choice of dimensionality of trade models influences the equilibrium.[4] Therefore it is not possible to simply extend a two commodity two factor trade model for factor mobility. The equilibria of these two models would not be comparable, standard theorems of trade theory would be valid in the one version of the model but not in the other. Therefore, an extension of a trade model for international factor

4 See Ethier (1984) and Ethier, Svensson (1986).

mobility would also require an adjustment of the dimensionality in order to keep the equilibria of both variants comparable. In the approach chosen here an extension to include international factor mobility is straightforward. Therefore, after discussing the basic model with international immobility an extension is considered with perfect international capital mobility.[5]

2.1. The Behavior of the Production Sector

The economy is assumed to consist of 2 sectors. Each sector faces perfect competition in the factor and output market and its firms maximize profits Π_i. Each sector produces one output good, Y_i, with the factors labor, L_i, capital, K_i, and emissions P_i, where $i = 1;2$. The output goods are both internationally tradable and can be sold at world market prices p_i, where p_1 is assumed to be the numeraire. Labor, capital and environment are mobile between sectors but immobile internationally. The factor prices are denoted w_L, w_K, and w_P, respectively.

Since there are no externalities between sectors individual profit maximization under perfectly competitive conditions implies that firms behave as if they were maximizing total profits of the production sector. It is assumed that the supply of labor and capital is inelastic, such that it can always be denoted with $\bar{L}$, and $\bar{K}$, respectively. Pollution P is a by-product of production for which the production sector has to pay a price w_P to the government. The price for pollution, w_P, is a policy instrument for the government.

Next, this section gives a heuristic derivation of the national product function which has become an important tool in modern trade theory.[6] Under the assumption that there are no externalities between firms in the production sector, individual profit

[5] Examples for this extension may be found in Woodland (1982) and Ethier, Svensson (1986).

[6] Other introductions into the concept of national product functions are given in Dixit, Norman (1980), or Woodland (1982).

maximization is equivalent to joint profit maximization. Since under the assumption of constant returns to scale profits for each firm are zero, the behavior of the firms of the economy can be summarized by the following maximization problem:

$$\sum_{i=1}^{n} \Pi_i = \max_{L_i;K_i;P_i} \left\{ \sum_{i=1}^{n} p_i Y_i - w_L L_i - w_K K_i - w_P P_i : Y_i \le F_i(L_i;K_i;P_i) \right\} = 0,$$

where n denotes the number of firms. The market equilibrium requires that factor demand equals factor supply. This condition can be considered as follows:

$$\sum_{i=1}^{n} \Pi_i = \max_{L_i;K_i;P_i} \left\{ \sum_{i=1}^{n} p_i Y_i - w_L L_i - w_K K_i - w_P P_i : \right.$$
$$\left. Y_i \le F_i(L_i;K_i;P_i); \overline{L} = \sum_{i=1}^{n} L_i ; \overline{K} = \sum_{i=1}^{n} K_i \right\} = 0$$

The conditions for the factor market equilibrium allows the following rearrangement of the above function:

$$w_L \overline{L} + w_K \overline{K} = G(p; w_P; \overline{K}; \overline{L}) =$$
$$\max_{L_i;K_i;P_i} \left\{ \sum_{i=1}^{n} p_i Y_i - w_P P_i : Y_i \le F_i(L_i;K_i;P_i); \overline{L} = \sum_{i=1}^{n} L_i ; \overline{K} = \sum_{i=1}^{n} K_i : \right\} = 0$$

where for p we adopt vector notation such that p denotes the vector consisting of p_1 and p_2. The technological and endowment constraints of the above maximization problem is usually summarized by the notation $(Y,P) \in T(\overline{K},\overline{L})$, where $T(\overline{K},\overline{L})$ is called the technology set and Y denotes a vector consisting of Y_1, Y_2. The variable P denotes the sum of P_1 and P_2. The resulting function can now be summarized as follows in the so called national product function:[7]

$$(1) \qquad G(p, w_P, \overline{K}, \overline{L}) = \max_{Y,P} \{ pY - w_P P : (Y,P) \in T(\overline{K},\overline{L}) \}.$$

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[7] See Dixit, Norman (1980), or Woodland (1982) for mathematically precise descriptions of the national product function. The approach of this section attempts to be a constructive and intuitive derivation of the national product function.

The convenience of national product function results from application of the envelope theorem that delivers all the endogenous variables needed to obtain comparative static results. Differentiation of the national product function with respect to the prices p_1, p_2 delivers the outputs Y_1, Y_2, respectively. Differentiation with respect to the factor endowments yields the respective factor prices. Differentiation with respect to w_P delivers $-P$. It is well known that $G(p, w_P, \overline{K}, \overline{L})$ is concave in $\overline{K}$ and $\overline{L}$ and convex in p, and w_P.

The national product function $G(p, w_P, \overline{K}, \overline{L})$ also includes the public good character of pollution. If pollution were a private good, as is assumed often in the literature[8], the national product function requires the inclusion of a factor endowment constraint for pollution $\overline{P}$. The national product function is now:

(2) $$\tilde{G}(p, \overline{P}, \overline{K}, \overline{L}) = \max_{Y}\{pY : Y \in \tilde{T}(\overline{P}, \overline{K}, \overline{L})\},$$

where $\tilde{T}(\overline{P}, \overline{K}, \overline{L})$ is a strictly convex technology set.

The difference in the assumption about rivalry in the use of pollution, changes also environmental policy instruments. In the public good model environmental policy consists in changing the price for pollution, w_P, which is exogenous. Firms then change their production inputs and the endogenous variable P changes as a result.

In the pollution as a private good model, the optimum conditions of the production sector require that all of the endowment of $\overline{P}$ is used for production. The only way how government policy can change the level of pollution is by changing the endowment of the economy. This means the environmental policy instrument is the exogenous variable $\overline{P}$. The derivation of $\tilde{G}(p, \overline{P}, \overline{K}, \overline{L})$ with respect to $\overline{P}$ delivers the now endogenous price for using pollution in production, $\tilde{w}_P$. For the rest of this paper

[8] See e.g. Eichberger, Gronych, Pethig, Siebert (1980), Rauscher (1997).

pollution is considered as a public good. A change in this assumption is straightforward.[9]

Very important for the comparative statics in Heckscher-Ohlin Trade models are the so called Rybczynski and Stolper-Samuelson theorems.[10] The Rybczynski theorem gives comparative static results for the reaction of output after the factor endowment of the economy has changed under the assumptions of constant product prices. With the national product function these reactions are found very easily. The output for each sector is found after differentiating the national product function with respect to the output prices. In the pollution as public good case we have:

$$Y_i = G_{p_i}\left(p, w_P, \overline{K}, \overline{L}\right), \qquad i = 1;2.$$

In the pollution as private good case we have:

$$Y_i = \tilde{G}_{p_i}\left(p, \overline{P}, \overline{K}, \overline{L}\right), \qquad i = 1;2.$$

Differentiation of the output with respect to the factor endowment gives the desired reactions of output to an increase in the factor endowment. The Rybczynski theorem states that the output of sector i increases if this sector uses the factor whose endowment is increased relatively intensively to other sectors. We use this theorem as a definition for factor intensity. Consider for example a change in the endowment of labor, $\overline{L}$. Sector i is labor intensive, if the derivative $G_{p_i\overline{L}}\left(p, w_P, \overline{K}, \overline{L}\right)$, or $\tilde{G}_{p_i\overline{L}}\left(p, \overline{P}, \overline{K}, \overline{L}\right)$, respectively, is positive. These derivatives are the so-called Rybczynski derivatives. If this derivative is negative, sector i is labor extensive.

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9 If environment is considered as a private good the dimensionality of the model would have to be changed such that the number of goods equals the number of private production factors, i.e. a third production sector would be needed. This extension generates an equilibrium that would yield the validity of the classic theorems of trade theory. See Ethier (1984) or Jones (1987) and also the appendix to this paper for details.

10 Stolper, Samuelson (1941) and Rybczynski (1955) were the first to analyze the effects of product prices and endowment on factor prices and output, respectively.

The Stolper-Samuelson theorem says how factor prices react to a change in output prices under the assumption that endowments remain constant. Since factor prices are found by differentiating the national product function with respect to endowment, the desired reactions are described by the so called Stolper-Samuelson derivatives and which are the following second derivatives of the national product function:

$$\frac{dw_X}{dp_i} = G_{Xp_i}\left(p, w_P, \overline{K}, \overline{L}\right), \qquad i = 1;2, \text{ and } X = \overline{K}, \overline{L},$$

in the pollution as public good case, and

$$\frac{dw_X}{dp_i} = \tilde{G}_{Xp_i}\left(p, \overline{P}, \overline{K}, \overline{L}\right), \ i = 1;2, \text{ and } X = \overline{K}, \overline{L},$$

in the pollution as private good case. One can also see that the Rybczynski and Stolper-Samuelson derivatives are identical.[11]

In the environment as a private good case one could define pollution intensive and extensive sectors in an analogous way as labor intensive and extensive sectors. However, in the pollution as a public good case this is not so obvious. In this model the output effects of environmental policy are:

$$(3) \qquad \frac{dY_i}{dw_P} = G_{p_i w_P}\left(p, w_P, \overline{K}, \overline{L}\right) = -\frac{dP}{dp_i}, \qquad i=1, 2.$$

An increase in the price of pollution, w_P, will reallocate the capital and labor endowment of the economy between the two sectors. If the output of sector i increases after raising w_P, the contracting influence of the cost increase is overcompensated by drawing more of the resources to this sector. This sector is called pollution extensive. If the reallocation of resources in the economy is not able to compensate the contracting impact of the increase in the price of pollution the sector is called pollution intensive.[12]

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11 See Dixit, Norman (1980) for the terms Stolper-Samuelson and Rybczynski derivatives, respectively.

12 This line of argumentation is adopted from Copeland (1994).

An alternative intuition for this definition is offered by $-dP/dp_i$. An increase in p_i will increase the output of sector i by drawing more resources away from the rest of the economy towards the sector i. This will also change the pollution level of the economy. If the expanding part of the economy increases its pollution more than the contracting part, the expression dP/dp_i is positive. In this case the sector i is called pollution intensive.[13]

From these definitions follows that sector i is pollution intensive if in the environment as a private good case $\tilde{G}_{p_i\overline{P}}(p,\overline{P},\overline{K},\overline{L})$ is positive and in the environment as public good case if $G_{p_i w_P}(p,w_P,\overline{K},\overline{L})$ is negative.

The next section introduces the household sector.

2.2. The Behavior of the Household Sector

The economy consists of one household sector. Assuming that all households are identical in preferences and endowment, the sector is sufficiently described by a representative household. The representative household maximizes a utility function which contains the consumption of the two tradable output goods, which are denoted with C_1 and C_2 and that are summarized in the vector C. Consumption is financed by income that is obtained from rental of capital, labor, which is supplied inelastically and lump sum transfer from the government. The lump sum transfer from the government is financed by taxation of the production input environment. Thus, the households receive all factor payments as income. The household behavior is described by the following minimum expenditure function:

(4) $$E(u,p;Z)=\min_{C}\{pC:u\le U(C;Z(P))\}.$$

[13] See also here Copeland (1994).

The expression $Z(P) = P$ describes the externality from using environment in production. The smaller the amount of environment used for production the larger the utility. Hence, $U_Z < 0$, and consequently $E_Z > 0$. Differentiation of $E(u,p;Z)$ with respect to the commodity price vector p_i yields the compensated demand functions of the private consumption good i, with i=1,2. If utility is weakly separable between private consumption and environmental quality, demand for C is independent of environmental quality. However, in general, this paper assumes that private consumption and environmental quality are not separable, thus in general $E_{pZ} \neq 0$. Differentiation of the minimum expenditure function with respect to utility u gives the additional income that is necessary to obtain the additional utility. It is clear that $E_u > 0$.

The rest of this paper analyzes the impacts of domestic environmental policies on welfare and different measures of international competitiveness. The case of environment as a private good is neglected, since it is very similar to the case of environment as a public good.

2.3. Environmental Policy in the Small Country Case

This section describes the equilibrium under the assumptions of a small open economy that takes world market prices as given.[14] The effects of environmental policy on welfare and competitiveness are discussed. Environmental policy consists of increasing the price for environment w_P. The effect on welfare is measured by changes in utility u. International competitiveness of a sector is measured by its revenue $p_i Y_i$, $i = 1;2$.

The equilibrium is described by the following equations:

(5a) $E(u, p;Z) = G(p, w_P, \overline{K}, \overline{L}) - w_P G_{w_P}$,

[14] A comprehensive treatment of this model is given in Woodland (1982), Ch. 6 for the case without environment. For a treatment that includes environmental externalities, but analyzes only welfare impacts of environmental policies, see Copeland (1994).

(5b) $M = E_{p_2} - G_{p_2}$,

where $Z = -G_{w_P}$ and M denotes the import of commodity 2. For brevity, the arguments of differentiated functions are left out. Equation (5a) describes the income equation of the household. The expenditure for all consumption commodities has to equal the household income. The household income equals, as previously noted, the factor payments of the production sector. The tax payments of the firms for pollution cancel out, since the government gives this tax revenue in a lump sum fashion to the household sector. Expression (5b) gives a definition of the net import of commodity 2. The difference between domestic demand and domestic output must equal the import of the respective commodity. The corresponding equation for commodity 1 is redundant due to Walras' law. The endogenous variables are utility u, and the net import of commodity 2, M. Thus, two equations solve two variables.

Environmental policy consists of raising w_P. From equation (5a) follows the effect on welfare of environmental policy after differentiation:

$$(6) \qquad \frac{du}{dw_P} = \frac{E_Z - w_P}{E_u} G_{w_P w_P}.$$

Welfare u is affected through two channels. Both channels, result from the decrease of pollution P. The decrease of P reduces the negative externality from production and, hence, increases welfare, which is expressed by $G_{w_P w_P} E_Z / E_u$.[15] The decrease of P also reduces the factor income of the households and thus affects welfare negatively. The change in income results from two sources: First the increase of w_P causes a redistribution of resources from firms to the government. However, since the households receive all factor income and government tax revenue this effect does not influence household utility and cancels out. The second source measures the reduction of factor income due to substitution and contraction of output on the production side. This is expressed by $-G_{w_P w_P} w_P / E_u$. If w_P is such that pollution is completely

[15] Due to convexity in prices $G_{w_P w_P}$ is positive.

internalized, the effect of a marginal increase in w_P is zero. This is the case for $w_P = E_Z$ which equals the Pigou-tax rate. If w_P is smaller (greater) than the Pigou tax rate, welfare increases (decreases) after an increase in w_P.

The rest of this section analyzes the effects of environmental policy on the international competitiveness of the economy. This requires a definition of international competitiveness.

In the Heckscher-Ohlin model trade is driven by comparative advantage. In a two commodity model a country exports commodity 1 if the production is cheaper in terms of commodity 2. That is, commodity 1 is exported if the domestic country has to renounce less units of commodity 2 by reallocating resources from sector 2 to sector 1 than the rest of the world. The effects of international competitiveness may then be measured by their impact on the net import, but holding the terms of trade constant.[16] The terms of trade should be held constant, because otherwise one would measure also the changes in net imports that are brought about solely by a change in terms of trade. Changes in the terms of trade are already a consequence of changes in the competitiveness. In the small country model the terms of trade are always constant. Differentiation of the net import, M gives:

$$(7) \qquad \frac{dM}{dw_P} = -E_{pZ}G_{w_P w_P} - G_{pw_P}.$$

There are two sources that affect this indicator for international competitiveness. The first source, $-E_{pZ}G_{w_P w_P}$, describes the effect of improved environmental quality on demand. An increase in w_P reduces pollution and thus increases environmental quality. If this change in environmental quality affects demand negatively, net imports will decrease and thus the indicator for competitiveness is affected positively. For example the demand for tourism, which is an import good, might be affected negatively, i.e. households stay home, if the environmental quality at home improves. However, if environmental quality and private consumption goods are weakly

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16 This definition is used by Jaffe, Peterson, Portney, Stavins (1995). See also Tyson (1988).

separable, this effect is always zero. The second source, $-G_{pw_P}$, describes the supply side effect of domestic environmental regulation. Competitiveness is affected positively, if the sector is pollution extensive as follows from the above definitions.

Another measure for the international competitiveness of a sector might be its revenue. For a small open economy which faces exogenous terms of trade, output is an equivalent measure. The output measure is also an indicator for the market share. Output can be written as:

$$Y_i = G_{p_i}\left(p, w_P, \overline{K}, \overline{L}\right), \qquad \text{where } i=1,2.$$

It follows from the definition of pollution intensity that an increase in the domestic environmental regulation increases the output of the pollution extensive sectors and decreases the output of the pollution intensive sectors.

2.4. Environmental Policy in the Two Country Case

This section describes the equilibrium in a two country case.[17] In addition to the preceding section it is assumed that the public good environmental quality is weakly separable from the private consumption goods. This amounts to assuming $E_{pZ} = 0$. This seems justified since non-separable preferences for consumption goods and environmental quality might change comparative static results in either direction.[18] The equilibrium conditions are:

(8a) $$E(u, p; Z) = G\left(p, w_P, \overline{K}, \overline{L}\right) - w_P G_{w_P} + Tr,$$

(8b) $$E^*\left(u^*, p, Z^*\right) = G^*\left(p, w_P{}^*, \overline{K}^*, \overline{L}^*\right) - w_P^* G_{w_P}^* - Tr,$$

(8c) $$G_{p_2} + G_{p_2}^* = E_{p_2} + E_{p_2}^*,$$

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[17] See Dixit, Norman (1980), or Woodland (1982) for a comprehensive treatment of this model without environmental externalities.

[18] Besides this, it is a very common assumption in environmental economics.

where $Z = -G_{w_P}$ and $Z^* = -G^*_{w_P}$. The equations (8a)-(8c) determine the equilibrium values of u, u^*, and p_2. Note that as commodity 1 is the numeraire its price p_1 is normalized. For brevity the arguments of the differentiated functions are left out. The variable Tr denotes a transfer that the foreign country gives to the domestic country. This variable is introduced in order to facilitate the comparative statics.

From the differentiation of equilibrium condition (8a) with respect to u, p_2, and w_P one can derive the effect of domestic environmental regulation on domestic welfare:

$$(9) \qquad \frac{du}{dw_P} = \frac{E_Z - w_P}{E_u}\left(G_{w_P w_P} + G_{w_P p_2}\frac{dp_2}{dw_P}\right) - \frac{M}{E_u}\frac{dp_2}{dw_P},$$

where $M = E_{p_2} - G_{p_2}$ denotes the import of commodity 2 in the domestic country. The term in the brackets in expression (9) describes the total reaction of pollution after an increase in w_P. This term takes account of the effect that a change in terms of trade has on the economy. Under normal circumstances it should be positive, because otherwise pollution could be decreased by cutting w_P.[19] However, compared to the small economy this effect of the terms of trade on pollution affects the magnitude of the welfare gains from an increase in w_P. An increase in the terms of trade implies a positive effect on welfare if $(E_Z - w_P)$ and $G_{w_P p_2}$ are of the same sign. A negative value of $G_{w_P p_2}$s implies that the pollution in the domestic economy increases after an increase in terms of trade. This increases the tax base for the lump-sum transfers. The effect on welfare, however, is positive if the households perceive the increase in the lump sum transfer as an overcompensation for the increased level of pollution. If $G_{w_P p_2}$ is positive, pollution decreases, and, hence, also the tax basis of the lump-sum transfer. This has a positive impact on welfare if the households value the decrease in the pollution higher than the decrease in the lump-sum transfer.

The second term denotes the terms of trade effect. An increase in w_P will change the supply of the domestic production sector. This will in turn affect the terms of trade.

[19] As the later analysis makes clear the two terms in the brackets are always of opposite sign. Therefore, on theoretical grounds it cannot be excluded that pollution increases after an increase in environmental regulation. Rauscher (1997) considers also this possibility.

The terms of trade affect domestic welfare through the trade balance. Under the assumption that environmental regulation increases the terms of trade p_2, this channel tends to affect domestic welfare positively if M is negative, i.e. that the domestic country is a net exporter of commodity 2. If the domestic country is a net importer of commodity 2, than the terms of trade have to decrease in order to affect welfare positively through this channel. The reason for this is that if the home country exports commodity 2 an increase in the terms of trade means that a given quantity of commodity 1 can be exchanged for a smaller quantity of commodity 2. If the domestic country imports commodity 2 it has to give more of commodity 1 in order to receive the same quantity of commodity 2 after an increase in the terms of trade. In the Heckscher-Ohlin world a country always exports the commodity where it has a comparative advantage and imports the commodities where it has a comparative disadvantage. Thus, one can say that environmental policy tends to affect welfare positively if it increases the value of the comparative advantage or reduces the value of the comparative disadvantage.

From the differentiation of equilibrium condition (8b) with respect to u, p_2, and w_P one can derive the effect of domestic environmental regulation on foreign welfare:

$$(10)\quad \frac{du^*}{dw_P} = \frac{E_Z^* - w_P^*}{E_u^*} G_{w_P p_2}^* \frac{dp_2}{dw_P} - \frac{M^*}{E_u^*}\frac{dp_2}{dw_P},$$

where $M^* = E_{p_2}^* - G_{p_2}^*$ denotes the net import of commodity 2 of the foreign country. It is related to the domestic net import of commodity 2 by $M + M^* = 0$. Expression (10) describes the effect of a unilateral increase in domestic environmental regulation on foreign welfare. In the absence of any transboundary pollution this expression consists only of a terms of trade effect. The interpretation of is analogous to the interpretation of the terms of trade effect on domestic welfare in equation (9) and therefore omitted.

We have seen that the effect of environmental regulation on the terms of trade, p, plays an important role in the determination of the effects of unilateral environmental regulation on the welfare in both countries. The sign of the change in terms of trade results from the interaction of the production technology in both countries and the preferences of the households. In order to determine the sign of the terms of trade effect one can differentiate (8a)-(8c) to obtain the following equation system:

$$(11)\quad \begin{pmatrix} E_u & 0 & M+(w_P-E_Z)G_{w_P p_2} \\ 0 & E_u^* & M^*+(w_P^*-E_Z^*)G_{w_P p_2}^* \\ -E_{p_2 u} & -E_{p_2 u}^* & S_{p_2 p_2} \end{pmatrix} \begin{pmatrix} du \\ du^* \\ dp_2 \end{pmatrix} = \begin{pmatrix} -(w_P-E_Z)G_{w_P w_P}dw_P + dTr \\ -dTr \\ -G_{p_2 w_P}dw_P \end{pmatrix},$$

where $S_{p_2p_2} = \left(G_{p_2p_2} - E_{p_2p_2} + G_{p_2p_2}^* - E_{p_2p_2}^*\right) \geq 0$ as a consequence of the curvature characteristics of the GNP function and the minimum expenditure function. In order to determine the sign of the determinant Det in (11) we assume that $du/dTr > 0$ and $du^*/dTr < 0$.[20]

$$(12)\quad \frac{du}{dTr} = \frac{1}{Det}\left[E_u^* S_{p_2p_2} + E_{p_2u}^*\left(w_P^* - E_Z^*\right)G_{w_P p_2}^* + E_{p_2u}^*(w_P - E_Z)G_{w_P p_2}\right].$$

The signs of the expressions $\left(w_P^* - E_Z^*\right)G_{w_P p_2}^*$ and $(w_P - E_Z)G_{w_P p_2}$ depend on the environmental policy of the respective country. Especially, it is important how far w_P is away from its Pigou level E_Z. We assume that the environmental policy is always sufficiently close to the optimal level such that the signs of the expressions $\left(w_P^* - E_Z^*\right)G_{w_P p_2}^*$ and $(w_P - E_Z)G_{w_P p_2}$ is not decisive for the nominator of (12). With this assumption the nominator in (12) is positive such that $du/dTr > 0$ implies $Det > 0$.[21] Now we can analyze the effects of environmental regulation on the terms of trade or equivalently the world market price for commodity 2, p_2:

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20 This assumption is a very helpful device in order to facilitate the comparative static analysis considerably. Similar assumptions are used for example in Dixit, Norman (1980).

21 It should be noted that the assumption $du/dT > 0$ would not be needed under the assumption of homothetic preferences, which imply $E_{pu} = E_{pu}^* = 0$. With homothetic preferences the determinant would be unambiguously positive. Note that the assumption $du/dT > 0$ is not as

(13) $\frac{dp_2}{dw_P} = \frac{1}{Det} E_u^* \left(-E_u G_{p_2 w_P} - E_{p_2 u} (w_P - E_Z) G_{w_P w_P} \right).$

If we maintain the convention that environmental policy is in both countries sufficiently close to its Pigou level or that preferences are homothetic which implies $E_{p_2 u} = E^*_{p_2 u} = 0$, such that the term $(w_P - E_Z)$ never influences the sign of any of the multiplicators, the sign of the price reaction is also here determined alone by the sign of $G_{p_2 w_P}$. As it is intuitively clear, with increasing supply of commodity 2, $G_{p_2 w_P} > 0$, its relative world market price falls, otherwise it increases.

Next the effects of environmental regulation on the various indicators of international competitiveness are analyzed. The changes in net imports are given by the following expression:

$$\frac{dM}{dw_P} = \left(E_{p_2 p_2} - G_{p_2 p_2} \right) \frac{dp_2}{dw_P} - G_{p_2 w_P}.$$

The changes in net imports result from a terms of trade effect that affects the demand and the supply side and a direct effect of environmental policy. Since the minimum expenditure function is concave and the national product function is convex in p the term in the brackets is unambiguously negative. The effect of environmental regulation on the terms of trade is of the same sign as $G_{p_2 w_P}$. Since $G_{p_2 w_P}$ is positive (negative) if the production of commodity 2 is pollution extensive (intensive) thus in this case net imports of commodity 2 decrease (increase). Equilibrium requires a balanced trade account, hence, the net import of commodity 1 goes into the opposite direction. A comparison of the two country model with the small open economy shows that the sign of net import change are always the same in both models. Consequently, for this indicator it does not matter if the terms of trade effect is considered or not.

The revenue change in each sector is determined by:

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restrictive as it might seem. The transfer does not affect factor prices. It is straightforward to show that when $du/dT > 0$ also $du^*/dT < 0$.

(14) $$\frac{dY_1}{dw_P} = G_{p_1 w_P} + G_{p_1 p_2}\frac{dp_2}{dw_P},$$

(15) $$\frac{dp_2 Y_2}{dw_P} = p_2 G_{p_2 w_P} + \left(G_{p_2} + p_2 G_{p_2 p_2}\right)\frac{dp_2}{dw_P}.$$

In (14) and (15) the first term always describes the direct effect of environmental regulation on the output of the industry. The second term describes the terms of trade effect. As for the small open economy the first effect is positive or negative depending whether the industry is pollution extensive or intensive. As was shown above, if environmental policy in each country is sufficiently close to its Pigou level the terms of trade are increasing (decreasing) if the domestic industry of commodity 2 is pollution intensive (extensive). Given that $G_{p_2} + p_2 G_{p_2 p_2}$ must be positive and that an increase in the terms of trade implies $G_{p_2 w_P}$ to be negative, the sign of (15) is ambiguous since both terms are always of opposing sign. It cannot be excluded that an increase in w_P is overcompensated by the terms of trade effect. That is, even if the industry for commodity 2 is pollution intensive (extensive) the revenue of that sector might still increase (decrease) if the terms of trade effect is strong enough.

Also the sign of (14) may be ambiguous. It is clearly positive (negative) if sector 1 is pollution extensive (intensive) and, given that $G_{p_1 p_2} < 0$, the terms of trade fall (increase). One can exclude a decrease in terms of trade when sector 1 is pollution extensive. If sector 1 is pollution extensive this implies that $G_{p_1 w_P} > 0$. A decrease in the terms of trade implies $G_{p_2 w_P} > 0$. But since it is impossible that both sectors increase output after an increase in w_P, it is impossible that $G_{p_1 w_P}$ and $G_{p_2 w_P}$ are positive at the same time.

At the end of this section another point should be emphasized regarding the incentive of governments to impose environmental regulation on the economy. Equation (9) gives the reaction of welfare to an increase in environmental regulation. A government that wants to maximize domestic welfare should raise w_P until du/dw_P equals zero. Therefore, a welfare maximizing government should set w_P such that:

$$(16) \quad \frac{E_Z - w_P}{E_u}\left(G_{w_P w_P} + G_{w_P p_2}\frac{dp_2}{dw_P}\right) = \frac{M}{E_u}\frac{dp_2}{dw_P}.$$

The term in the brackets gives the total reaction of pollution after an increase in w_P including the feedback effects induced by the changes of the terms of trade. It is reasonable to assume that this term is always positive otherwise the government would reduce pollution by cutting w_P. From (16) one can conclude that for a large country it is in general not optimal to set the price for emission equal to the Pigou level. Environmental policy should set w_P above (below) the Pigou level if $\frac{M}{E_u}\frac{dp_2}{dw_P}$ is negative (positive).[22] From the above analysis follows that $\frac{M}{E_u}\frac{dp_2}{dw_P}$ is positive (negative) if the domestic country imports (exports) the pollution intensive commodity or exports (imports) the pollution extensive commodity. The reason for this policy conclusion is that in a large open economy environmental policy has two effects, namely the effect on the level of pollution, but also the effect on the terms of trade. Thus, in evaluating environmental policy it is not enough to see whether the improvement in environmental quality exceeds the change in factor income. Income of the household changes also as a result of the change in the terms of trade. Therefore, it might be optimal for a country to do more or less for its environment than traditional environmental policy analysis suggests. However, since $M = -M^*$ one can conclude that if it is optimal for the domestic country to set w_P above (below) the Pigou level then it is optimal for the foreign country to exactly the opposite. Only if there is no trade between both countries or they cannot influence their terms of trade it is optimal for both countries to set w_P equal to the Pigou level. One can conclude that if it is optimal for one country to be dirty, i.e. $E_Z > w_P$, than there always exists another country for which it is optimal to be clean, i.e. $E_Z^* < w_P^*$.[23]

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[22] This is true under the assumption that an increase in environmental regulation reduces domestic pollution. The statement revereses if an increase in environmental regulation raises domestic pollution.

[23] See Rauscher (1997). This result also follows from Markusen (1975), and Krutilla (1991).

3. Environmental Policy in the Presence of International Capital Mobility

This section extends the analysis of the previous section to include perfect capital mobility. This extension allows an analysis of the impacts of environmental regulation on international capital flows. The consideration of international capital flows are important because in the public debate foreign direct investment is understood as an indicator of international competitiveness.

This section considers environment only as a public good. Two modifications compared with the preceding section are necessary. As already mentioned the dimensionality has to change in order to preserve a minimum of comparability to the preceding section.[24] Thus, the model includes as before two commodities that are produced and two types of labor, skilled, $\overline{L}_S$, and unskilled, $\overline{L}_U$. The prices for skilled and unskilled labor are w_{LS}, and w_{LU}, respectively. The model requires a modification with respect to the national product function which has to consider that capital can be exported. It follows a heuristic derivation: Starting point is the function $G(p, w_P, \overline{K}, \overline{L})$ from the preceding section with one important difference. Capital endowment, $\overline{K}$, is no longer an argument of $G(p, w_P, \overline{K}, \overline{L})$. Since capital is internationally mobile, capital used for domestic production may differ from the domestic capital endowment, $\overline{K}$. Therefore, the equivalent to $G(p, w_P, \overline{K}, \overline{L})$ is now:

$$\tilde{G}(p, w_P, K, \overline{L}_S, \overline{L}_U) = \max_{Y,P}\left\{pY - w_P P : Y \in T(K, \overline{L}_S, \overline{L}_U)\right\}.$$

The derivative of $\tilde{G}(p, w_P, K, \overline{L}_S, \overline{L}_U)$ gives still the rental price for capital w_K, which is, however, not determined any longer, domestically, but on the international capital market. Thus, an additional equilibrium condition for the production sector requires:

$$w_K = \tilde{G}_K.$$

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[24] This is demonstrated in the appendix, but can be also found in Ethier, Svensson (1986).

The minimum expenditure function does not change. However, income of the household is extended for capital income by export. Therefore, the household receives income from inelastically supplied skilled and unskilled labor, from lump sum transfers, from renting capital to domestic firms and foreign firms.

The next two sections analyze the effects of environmental policy in the small open economy and the two country setting. Pollution is always assumed to be a public good and preferences of households are weakly separable between environmental quality and consumption.

3.1. Environmental Policy in the Small Country Case

In the presence of international capital mobility, the equilibrium of a small open economy is described by the following equations:

(17a) $E(u,p;Z)=\tilde{G}(p,w_P,K,\overline{L}_S,\overline{L}_U)-w_P\tilde{G}_{w_P}+w_K(\overline{K}-K)$,

(17b) $w_K=\tilde{G}_K$,

(17c) $M=E_{p_2}-\tilde{G}_{p_2}$,

where $Z=-\tilde{G}_{w_P}$. Again, the net import equation for commodity 1 can be omitted. Equation (17a) describes the income equation of the household. Household expenditure has to equal household income. Compared to the preceding section a new source of household income is the income from net capital exports, $\overline{K}-K$. Equation (17b) describes the arbitrage condition which implies that the world rental price of capital has to equal the domestic marginal productivity of capital. (17c) is the known definition of net imports. The endogenous variables are welfare u, domestic capital input K and the net import of commodity 2, M.

The impact of environmental regulation on domestic welfare can be assessed by differentiation of equations (17a) and (17b):

$$(18) \quad \frac{du}{dw_P} = \frac{E_Z - w_P}{E_u}\left(\tilde{G}_{w_P w_P} + \tilde{G}_{w_P K}\frac{dK}{dw_P}\right),$$

where $dK/dw_P = -\tilde{G}_{Kw_P}/\tilde{G}_{KK}$. The term in the brackets in equation (18) gives the total reaction of pollution after an increase in w_P. This total reaction includes the effect that the change in domestic capital use has on pollution. In the rest of this paper we call this effect the capital export effect. Due to the concavity of $\tilde{G}(p, w_P, K, \bar{L}_S, \bar{L}_U)$ in K it is guaranteed that pollution always decreases when w_P increases, thus the terms in the brackets is always positive. This leads to the same conclusion as in the preceding section. Environmental regulation increases welfare as long as w_P is below E_Z. However, compared to the small country model where factors are internationally immobile the welfare gain of an increase in w_P is larger when factors are mobile as a comparison between (6) and (18) shows. In this case globalization increases the possible welfare gains of environmental policy when initially the emission tax is below the Pigou solution.[25]

The reaction of domestic use of capital is described by $dK/dw_P = -\tilde{G}_{Kw_P}/\tilde{G}_{KK}$. The sign of this expression is completely determined by the derivative $\tilde{G}_{Kw_P}$. If it is positive (negative) the domestic marginal productivity of capital increases after an increase in w_P. If the domestic marginal productivity of capital decreases, environmental regulation causes capital flight otherwise the domestic country becomes more attractive for foreign direct investment.

Now we attempt to say something about the sign of the derivative $\tilde{G}_{Kw_P}$. The derivative $\tilde{G}_{Kw_P}$ is similar to the Stolper-Samuelson derivative, if one interprets pollution as a joint output and w_P its negative price. However the important difference is that the Stolper-Samuelson derivative considers only a change in the output price of one sector. But if one allows for the possibility of differential taxation of both sectors,

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[25] This result was obtained before by Copeland (1994).

the national product function would be $\tilde{G}(p, w_{P_1}, w_{P_2}, K, \bar{L}_S, \bar{L}_U)$. In this case $\tilde{G}_{K\tilde{w}_{P_i}}$, i=1,2 gives the Stolper-Samuelson derivative $\partial w_K / \partial w_{P_i}$.[26] Since w_{P_i} is a negative price the interpretation differs slightly from the standard interpretation: It is positive if sector i uses capital extensively and negative otherwise. The derivative $\tilde{G}_{K\tilde{w}_{P_i}}$ might be interpreted now as the derivative that occurs when both sectors of the economy experience the same increase in w_P, i.e. $dw_{P_1} = dw_{P_2}$:

$$\frac{dw_K}{dw_P} = \tilde{G}_{K\tilde{w}_P} = \sum_{i=1}^{2} \tilde{G}_{K\tilde{w}_{P_i}}$$

Therefore, $\tilde{G}_{Kw_P}$ may be considered as a measure of aggregate capital intensity. If it is positive the economy as a whole uses capital extensively, otherwise the economy is considered capital intensive. An increase in w_P changes optimal factor input in both sectors. It is possible that the marginal productivity of capital increases (decreases) in one (both) sector and decreases in the other sector. If the increase in the marginal productivity is stronger than the decrease the economy is capital extensive. Therefore, capital flight occurs if the economy as a whole uses capital intensively, but it is possible that the economy attracts more capital.[27]

The other possible indicators for international competitiveness are net imports and revenue. The impact on net imports is:

$$(19) \quad \frac{dM}{dw_P} = -E_{pZ}\tilde{G}_{w_P w_P} - \tilde{G}_{pw_P} - \tilde{G}_{pK}\frac{dK}{dw_P}.$$

Compared to the small open economy without capital mobility there is one additional effect to consider which results from the impact of environmental policy on foreign direct investment. Ceteris paribus, if foreign direct investment increases after raising

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26 Under the assumption of perfect capital mobility w_K is exogenous in the small country case. Therefore, the correct interpretation of $\partial w_K / \partial w_{P_i}$ is the ceteris paribus impact of w_{P_i} on the marginal productivity of capital. Thus, $\partial w_K / \partial w_{P_i}$ indicates the sign of the change of capital exports.

27 This result is in contrast to Rauscher (1997).

w_P, the net import decreases if the respective sector uses capital intensively. All other effects were already discussed in the small country model without capital mobility.

Revenue changes in both sectors are expressed by the following terms:

$$\frac{dY_1}{dw_P} = G_{p_1 w_P} + G_{p_1 K}\frac{dK}{dw_P},$$

$$\frac{dp_2 Y_2}{dw_P} = p_2 G_{p_2 w_P} + p_2 G_{p_2 K}\frac{dK}{dw_P}.$$

Also here no genuinely new effects are introduced. Compared to the model with capital immobility only the capital flow effect is new, but it works in the same way as in (19).

3.2. Environmental Policy in the Two Country Case

In the presence of international capital mobility, the equilibrium of the two country model is described by the following equations:

(20a) $E(u,p;Z) = \tilde{G}(p, w_P, K, \overline{L}_S, \overline{L}_U) - w_P \tilde{G}_{w_P} + w_K(\overline{K} - K),$

(20b) $E^*(u^*, p, Z^*) = \tilde{G}^*(p, w_P^*, K^*, \overline{L}_S^*, \overline{L}_U^*) - w_P^* \tilde{G}_{w_P}^* + w_K(\overline{K}^* - K^*),$

(20c) $K + K^* = \overline{K} + \overline{K}^*,$

(20d) $w_K = \tilde{G}_K,$

(20e) $w_K = \tilde{G}_K^*,$

(20f) $\tilde{G}_{p_2} + \tilde{G}_{p_2}^* = E_{p_2} + E_{p_2}^*.$

The only new equation here is (20c) which describes that in equilibrium world capital supply has to equal world capital demand. The endogenous variables are domestic and foreign welfare, domestic and foreign capital input, the world market rental price for capital, and the terms of trade p_2.

The impact of domestic environmental regulation on domestic welfare is found after total differentiation of (20a):

$$\text{(21)}\quad \frac{du}{dw_P}=\frac{E_Z-w_P}{E_u}\left(\tilde{G}_{w_P w_P}+\tilde{G}_{w_P p_2}\frac{dp_2}{dw_P}+\tilde{G}_{w_P K}\frac{dK}{dw_P}\right) -\frac{M}{E_u}\frac{dp_2}{dw_P}+\left(\overline{K}-K\right)\frac{dw_K}{dw_P}.$$

The term in the brackets of (21) gives the total reaction of pollution after an increase of w_P. This term includes the impact of the terms of trade effect and the capital export effect on pollution. Also here, capital mobility implies a greater decrease of pollution, compared to the two country model of the preceding section. A new effect is described by $\left(\overline{K}-K\right)dw_K/dw_P$. This effect work comparable to the terms of trade effect on the trade balance. If w_P increases the world rental price for capital and the economy is a net capital exporter this effect has a positive impact on welfare, because the domestic country gets a higher reward for exporting capital. Analogously, if w_P decreases the world rental price for capital the domestic economy is better off if it imports capital, because they become cheaper. All other effects are known and, thus, the interpretation is omitted.

The impact of domestic environmental regulation on foreign welfare is found after total differentiation of (20b):

$$\text{(22)}\quad \frac{du^*}{dw_P}=\frac{E^*_{Z^*}-w^*_P}{E^*_u}\left(\tilde{G}^*_{w_P p_2}\frac{dp_2}{dw_P}+\tilde{G}^*_{w_P K}\frac{dK^*}{dw_P}\right)-\frac{M^*}{E^*_u}\frac{dp_2}{dw_P}+\left(\overline{K}^*-K^*\right)\frac{dw_K}{dw_P}.$$

Also here the interpretation is analogous to the interpretation of (21), hence, it is omitted.

The impact of environmental regulation on the terms of trade and the capital flows is analyzed under the assumption that preferences in both countries are homothetic, i.e. $E_{p_2u} = E^*_{p_2u} = 0$:

$$\begin{pmatrix} E_u & 0 & \left[(K-\overline{K})\tilde{G}_{KK} + (w_p^* - E_Z^*)G^*_{w_PK}\right] & 0 & M + (w_P - E_Z)G_{w_Pp_2} \\ 0 & E_u^* & 0 & \left[(K^*-\overline{K}^*)\tilde{G}^*_{KK} + (w_p^* - E_Z^*)G^*_{w_PK^*}\right] & -M^* + (w_p^* - E_Z^*)G^*_{w_Pp_2} \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & \tilde{G}_{KK} & -\tilde{G}^*_{KK} & \left(\tilde{G}_{Kp_2} - \tilde{G}^*_{Kp_2}\right) \\ 0 & 0 & 0 & 0 & S_{p_2p_2} \end{pmatrix} \begin{pmatrix} du \\ du^* \\ dK \\ dK^* \\ dp \end{pmatrix}$$

$$= \begin{pmatrix} (E_Z - w_P)\tilde{G}_{w_Pw_P} dw_P + dT \\ -dT \\ 0 \\ -\tilde{G}_{Kw_P} dw_P \\ -\tilde{G}_{p_2w_P} dw_P \end{pmatrix}$$

The change in terms of trade after an increase in domestic environmental regulation is:

$$\frac{dp_2}{dw_P} = -\frac{\tilde{G}_{p_2w_P}}{S_{p_2p_2}}.$$

Also here we find that with homothetic preferences the term of trade increase if the domestic production of commodity 2 is pollution intensive. This result we also found in the two country model without capital mobility.

The change in domestic capital use is given by:

$$\frac{dK}{dw_P} = \frac{\tilde{G}_{p_2w_P}\left(\tilde{G}_{Kp_2} - \tilde{G}^*_{Kp_2}\right) - \tilde{G}_{Kw_P}S_{p_2p_2}}{S_{p_2p_2}\left(\tilde{G}_{KK} + \tilde{G}^*_{KK}\right)}.$$

The denominator of the term on the right hand side is always negative due to the curvature of the minimum expenditure and the national product function. The sign of the nominator depends on three expressions. First, it is important whether the terms of trade increase or decrease, $\tilde{G}_{p_2w_P}$. Second, it is important in which country the production of commodity 2 is more capital intensive, $\left(\tilde{G}_{Kp_2} - \tilde{G}^*_{Kp_2}\right)$. Thus, not the absolute capital intensity matters, but the relative capital intensity. And third, it is important whether the aggregate economy of the domestic country uses capital rather extensively or intensively, $\tilde{G}_{Kw_P}$.

If the expressions $\tilde{G}_{p_2 w_P}$ and $\left(\tilde{G}_{Kp_2} - \tilde{G}^*_{Kp_2}\right)$ are of opposite sign the situation is favorable for an increase of domestic capital use or equivalently, for an increase in foreign direct investment. If the terms of trade increase, that is $\tilde{G}_{p_2 w_P}$ is negative, then the impact on foreign direct investment is positive if the domestic country produces commodity two more capital intensive than the foreign country. An increase in the terms of trade raises the marginal productivity of capital in both countries above the real rental price of capital w_K/p_2. Therefore, in both countries capital demand increases in the first round. However, the demand increase is stronger where sector two uses capital more intensive.[28] Exactly the opposite mechanism takes place, when the terms of trade decrease. Then foreign direct investment increases if the foreign sector two uses capital more intensive than the domestic sector two, because, the marginal productivity of capital falls below the real rental price of capital w_K/p_2.

The second effect that is important is expressed by $\tilde{G}_{Kw_P}$ and affects only the domestic country. This effect captures the direct influence of environmental regulation on the domestic capital demand. This effect has a positive impact on foreign direct investment if the economy as a whole uses capital intensively. In this case an increase in w_P has a positive impact on domestic capital demand.

The other indicators for international competitiveness are net imports and revenue of the sectors: The change in net imports is given by:

$$(23)\quad \frac{dM}{dw_P} = \left(E_{p_2 p_2} - G_{p_2 p_2}\right)\frac{dp_2}{dw_P} - G_{p_2 w_P} - G_{p_2 K}\frac{dK}{dw_P}.$$

28 Also here the result is in contrast to Rauscher (1997).

If one follows the postulate of some economists[29] who want to exclude the terms of trade effects and the capital flow effects, the sign of the indicators depends only on the pollution intensity of the domestic sectors and the results are the same as in the model without capital mobility. Otherwise, a new effect has to be taken into account that results from the impact of the capital flows on the net import of the consumption commodities. If foreign direct investment increases after raising w_P, the net import decreases if the respective sector uses capital intensively. The terms of trade effect is already known and therefore not further interpreted.

Revenue changes in both sectors are expressed by the following terms:

$$\frac{dY_1}{dw_P} = G_{p_1p_2}\frac{dp_2}{dw_P} + G_{p_1w_P} + G_{p_1K}\frac{dK}{dw_P},$$

$$\frac{dp_2Y_2}{dw_P} = \left(G_{p_2} + p_2G_{p_2p_2}\right)\frac{dp_2}{dw_P} + p_2G_{p_2w_P} + p_2G_{p_2K}\frac{dK}{dw_P}.$$

Also here no genuinely new effects are introduced. Compared to the model with capital immobility only the capital flow effect is new, but it works in the same way as in (23).

Regarding the optimality of the Pigou solution in a large open economy we can make a similar point as in the two country model without capital mobility. Optimal environmental policy requires:

$$(24)\quad \frac{E_Z - w_P}{E_u}\left(\tilde{G}_{w_Pw_P} + \tilde{G}_{w_Pp_2}\frac{dp_2}{dw_P} + \tilde{G}_{w_PK}\frac{dK}{dw_P}\right) = \frac{M}{E_u}\frac{dp_2}{dw_P} - \left(\overline{K} - K\right)\frac{dw_K}{dw_P}.$$

Under the assumption that an increase of w_P reduces pollution, such that the term in the brackets on the left hand side is positive, over-regulation, $E_Z < w_P$, in the economy is positive if tighter environmental regulation increases the comparative advantage or reduces the comparative disadvantage. This is the case if the right hand side of (24) is negative. In other words if the exports (imports) of commodity 2 and the

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[29] See Tyson (1988), Jaffe, Peterson, Portney, Stavins (1995).

capital exports (imports) become more (less) expensive. If tighter environmental policy reduces the comparative advantage or increases the comparative disadvantage under-regulation is optimal. If the effect of environmental policy on terms of trade and the world market rental rate of capital are opposite in sign it is necessary to see which effect is more important in terms of household income and is simply evaluated by checking the sign of the right hand side of (24).

As in the two country model without capital mobility if there is one country that over-regulates there must be always another country that under-regulates.

4. Conclusions

The purpose of this paper was to study the impacts of unilateral environmental regulation of a production sector in a general equilibrium model of international trade. The focus was on the impacts of environmental regulation on welfare and various indicators of international competitiveness.

Traditional environmental policy analyses suggest that the first-best solution of environmental taxes should be set equal to the Pigou solution. In the Pigou solution the externality creating factor is taxed such that at the margin the tax revenue equals income equivalent of environmental quality. In a small open economy that faces exogenous terms of trade this policy is still optimal. However, in a large country that faces endogenous terms of trade this proposition does not hold any longer in general. The endogeneity of the terms of trade renders environmental policy as a potential instrument not only for environmental policy, but also for trade policy. Consequently, the first-best solution of environmental taxes should consider its influence on the terms of trade. This leads to the result that compared to the Pigou solution over- or under-regulation becomes optimal. However, the first-best solution of environmental taxes in different countries are always complementary. If in one country over-regulation is optimal then there always exists a second country for which under-regulation is the optimal solution.

In the public debate the fear is expressed that unilateral environmental regulation has negative impacts on the international competitiveness. This paper considered three indicators of international competitiveness: net imports, revenue, which indicated the market share, and foreign direct investment. Net imports and revenue are sectoral indicators that have to be calculated for each sector. The impact of international competitiveness on these indicators was analyzed in a small open economy that faces exogenous terms of trades and in a large open economy that faces endogenous terms of trade each with and without international capital mobility.

In the evaluation of the impacts of domestic policy on international competitiveness it is often argued that the appropriate measure is the identification of the effects holding world market prices constant. It is argued that otherwise one would measure changes in competitiveness that are brought about by changes in world market prices and not the domestic policy. For a small open economy this does not make any difference, because world market prices are constant, but for a large open economy it does. If one follows this line of argumentation net imports and revenue are equivalent indicators for international competitiveness. In all models it was found that the international competitiveness of a sector increases if it is pollution extensive. The pollution intensive sectors loose in international competitiveness. Foreign direct investment increases if the economy as a whole uses capital intensively. Thus, it is not necessarily true that environmental regulation induces capital flight.

If one considers also the indirect effects of environmental regulation that work through changes in world market prices on international competitiveness the results obtained for the large open economy might change. In this case the effects of the terms of trade and the world market rental price for capital might reverse the results compared to the case where they were neglected.

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Appendix Cost functions and equilibrium

Another important tool in modern trade theory is that of cost functions. The cost functions are helpful in giving the economic intuition behind the results of the comparative static analysis. Assuming a production function with constant returns to scale the behavior of each sector can be described by the profit function:

$$\Pi_i(p_i;w) = \min_{Y_i}\{p_i Y_i - Y_i C_i(w): Y \geq 0\},$$

where

$$C_i(w) = \min_{V_i}\{wV_i : Y_i = 1, (Y_i;V_i) \in T_i\},$$

describes the unit cost function of the production sector i where V_i denotes the vector of factor coefficients in the production of sector i. In equilibrium with perfect competition the following conditions must hold when all goods are produced:

$$p_i = C_i(w), \quad i=1,2.$$

This condition describes the well known marginal cost pricing condition. For given world market prices p_i, i=1,2, this equilibrium condition determines the factor price vector w. The factor supply of capital and labor is constrained for each period by the factor endowment of the economy. The factor demand functions follow from the cost functions. Thus, the factor market equilibrium is described by:

(25a) $C_{1w_L}(w)Y_1 + C_{2w_L}(w)Y_2 = \overline{L},$

(25b) $C_{1w_K}(w)Y_1 + C_{2w_K}(w)Y_2 = \overline{K}.$

for a given factor price vector w and endowment vector the factor market equilibrium conditions determine the sector outputs Y_1, and Y_2.

Pollution P is a public good that the production sector uses as an input in production. Thus, its demand is not constrained by endowment or a supply function. The production sector's demand, however, is finite, because the government charges a positive price w_P for emissions. The demand is, therefore, only regulated by government intervention. The demand for pollution by firms is described by:

$$C_{1w_P}(w)Y_1 + C_{2w_P}(w)Y_2 = P.$$

Now consider the 2 commodity model with capital, labor and pollution as the factors of production. The equilibrium is described by:

$$p_1 = C_1(w_L, w_K, w_P),$$

$$p_2 = C_2(w_L, w_K, w_P),$$

$$C_{1w_L}(w_L, w_K, w_P)Y_1 + C_{2w_L}(w_L, w_K, w_P)Y_2 = \overline{L},$$

$$C_{1w_K}(w_L, w_K, w_P)Y_1 + C_{2w_K}(w_L, w_K, w_P)Y_2 = \overline{K}.$$

The output prices p_1, p_2 and the endowment $\overline{L}$, $\overline{K}$ are exogenous. Note that this system of four equation is partially independent. The first two equations solve the endogenous factor prices only as functions of the output prices p_1, p_2. The second pair of equation solves the endogenous outputs Y_1, Y_2 only as functions of $\overline{L}$, $\overline{K}$. Factor prices depend on output prices and outputs depend on endowment. Therefore, with identical preferences in all countries export is determined only by the endowment. In a trade model where p_1, p_2 are world market prices and w_P is the same all over the world factor price equalization holds.

To obtain these characteristics of the equilibrium dimension is important. For example if there are three output goods factor prices would depend also on endowment and output would depend also on prices. Therefore, neither factor price equalization nor the Heckscher-Ohlin theorem would not be valid anymore.

With capital mobility w_K becomes a world market price that is determined by trade. Now the first pair of equation cannot determine the factor prices as functions of output prices alone. This pair of equations would be overdetermined. Thus, we divide labor into skilled and unskilled with factor prices w_{LS}, and w_{LU}. Then the first two equations form a system that is exactly determined. The second pair of equations is now:

$$C_{1w_L}(w_{LS}, w_{LU}, w_K, w_P)Y_1 + C_{2w_L}(w_{LS}, w_{LU}, w_K, w_P)Y_2 = \bar{L}_S,$$

$$C_{1w_L}(w_{LS}, w_{LU}, w_K, w_P)Y_1 + C_{2w_L}(w_{LS}, w_{LU}, w_K, w_P)Y_2 = \bar{L}_U,$$

$$C_{1w_K}(w_{LS}, w_{LU}, w_K, w_P)Y_1 + C_{2w_K}(w_{LS}, w_{LU}, w_K, w_P)Y_2 = K,$$

where K denotes the domestic demand for capital, which is endogenous for the domestic production sector. Therefore, if we consider capital mobility, we need to adjust the dimension of the model in order to preserve the characteristic of the equilibrium obtained in the version without capital mobility. In general terms, we need to choose a dimensionality where the number of international markets equals the number of private factor markets, such that an equilibrium exists where the standard theorems of trade theory maintain their validity. These theorems are the factor price equalization-, the Heckscher-Ohlin-, the Rybczynski-, and the Stolper-Samuelson-theorem.[30]

The rest of this section analyzes the effects of changes in the world market price vector p, the price of pollution w_P, and the endowment vector $W = (\bar{L}, \bar{K})$ on the output of the two sectors Y_1, Y_2, the pollution P and the factor price vector w. In order to analyze these effects, the rest of this section derives the Stolper-Samuelson derivatives $\partial w_i / \partial p_j$, $\partial w_i / \partial w_P$, where $i = K, L$, j=1,2.

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30 See Ethier (1984) or Jones (1987) for details.

Given our choice of numbers of goods and factors in the model without capital mobility, for given product prices and given emission price w_P, the factor prices are determined by:

$$p_1 = C_1(w_L; w_K; w_P),$$

$$p_2 = C_2(w_L; w_K; w_P).$$

Total differentiation leads to the following equation system:

$$(26) \quad \begin{pmatrix} \theta_L^1 & \theta_K^1 \\ \theta_L^2 & \theta_K^2 \end{pmatrix} \begin{pmatrix} \hat{w}_L \\ \hat{w}_K \end{pmatrix} = \begin{pmatrix} \hat{p}_1 - \theta_P^1 \hat{w}_P \\ \hat{p}_2 - \theta_P^2 \hat{w}_P \end{pmatrix},$$

where θ_i^j denotes the share of factor i in the cost of the production of commodity j. Note that $\sum_{i=K,L,P} \theta_i^j = 1$. A variable with a circumflex denotes a relative change. From (26) it is possible to obtain the Stolper-Samuelson derivatives. We are especially interested in $\partial w_i / \partial w_P$, where $i = K, L$:

$$(27) \quad \frac{\partial w_L}{\partial w_P} = \frac{\theta_K^1 \theta_P^2 - \theta_P^1 \theta_K^2}{\theta_L^1 \theta_K^2 - \theta_K^1 \theta_L^2} \frac{w_L}{w_P}, \quad \frac{\partial w_K}{\partial w_P} = \frac{\theta_P^1 \theta_L^2 - \theta_L^1 \theta_P^2}{\theta_L^1 \theta_K^2 - \theta_K^1 \theta_L^2} \frac{w_K}{w_P},$$

$$(28) \quad \frac{\partial w_K}{\partial w_P} = \frac{\frac{L^2}{P^2} - \frac{L^1}{P^1}}{\frac{L^1}{K^1} - \frac{L^2}{K^2}} \frac{P^1 P^2}{K^1 K^2}, \quad \frac{\partial w_L}{\partial w_P} = \frac{\frac{K^1}{P^1} - \frac{K^2}{P^2}}{\frac{L^1}{K^1} - \frac{L^2}{K^2}} \frac{P^1 P^2}{K^1 K^2}.$$

The denominator of (27) is positive if sector 2 is more capital intensive than sector 1, i. e. $K_2/L_2 > K_1/L_1$. This is what the rest of this section assumes. If sector 2 is more (less) pollution intensive than sector 1, i. e. $P_2/L_2 > P_1/L_1$ ($P_2/L_2 < P_1/L_1$) then the price for capital falls (rises) after an increase of the price for pollution. The change of the price for labor might be ambiguous. However, if sector 2 is more capital intensive and sector 1 is more pollution intensive, the price for labor falls unambiguously after an increase of the price for pollution. If sector 2 is more capital intensive and also more pollution intensive, the reaction of the price for labor is ambiguous. The sign of the reaction of the price for labor depends on:

$$\mathrm{sgn}\frac{\partial w_L}{\partial w_P} = \mathrm{sgn}\left(\frac{K^1}{P^1} - \frac{K^2}{P^2}\right) = \mathrm{sgn}\left(\frac{K^1}{L^1}\frac{L^1}{P^1} - \frac{K^2}{L^2}\frac{L^2}{P^2}\right).$$

The effects of environmental policy on the output of the production sector for given world market prices are obtained as follows: Differentiating equations (25a) and (25b) one obtains the following equation system for constant factor endowments:

$$(29)\quad \begin{pmatrix} s_L^1 & s_L^2 \\ s_K^1 & s_K^2 \end{pmatrix}\begin{pmatrix} \hat{Y}_1 \\ \hat{Y}_2 \end{pmatrix} = \begin{pmatrix} -\left[\eta_{LP} - \eta_{LL}\frac{\hat{w}_L}{\hat{w}_P} - \eta_{LK}\frac{\hat{w}_K}{\hat{w}_P}\right]\hat{w}_P \\ -\left[\eta_{KP} - \eta_{KL}\frac{\hat{w}_L}{\hat{w}_P} - \eta_{KK}\frac{\hat{w}_K}{\hat{w}_P}\right]\hat{w}_P \end{pmatrix},$$

where $\eta_{ij} = \left(s_i^1\eta_{ij}^1 + s_i^2\eta_{ij}^2\right)$ denotes the aggregate demand elasticity for factor i with respect to factor price j. The demand elasticities of the sectors are compensated demand elasticities that means output is assumed to remain constant. Therefore, from the definition of the Allen-Uzawa elasticity of substitution follows the following relationship between this demand elasticity and the elasticity of substitution $\eta_{ij}^n = \sigma_{ij}^n\theta_j^n$. The variable s_i^j denotes the demand share of sector j on the market for factor i. The expressions $\hat{w}_L/\hat{w}_P$ and $\hat{w}_K/\hat{w}_P$ are obtained from (27). From expression (29) one obtains:

$$(30a)\quad \frac{\partial Y_1}{\partial w_P} = \frac{\left[\eta_{KP} - \eta_{KL}\frac{\hat{w}_L}{\hat{w}_P} - \eta_{KK}\frac{\hat{w}_K}{\hat{w}_P}\right]s_L^2 - \left[\eta_{LP} - \eta_{LL}\frac{\hat{w}_L}{\hat{w}_P} - \eta_{LK}\frac{\hat{w}_K}{\hat{w}_P}\right]s_K^2}{s_L^1 s_K^2 - s_L^2 s_K^1}\frac{Y_1}{w_P},$$

$$(30b)\quad \frac{\partial Y_2}{\partial w_P} = -\frac{\left[\eta_{KP} - \eta_{KL}\frac{\hat{w}_L}{\hat{w}_P} - \eta_{KK}\frac{\hat{w}_K}{\hat{w}_P}\right]s_L^1 - \left[\eta_{LP} - \eta_{LL}\frac{\hat{w}_L}{\hat{w}_P} - \eta_{LK}\frac{\hat{w}_K}{\hat{w}_P}\right]s_K^1}{s_L^1 s_K^2 - s_L^2 s_K^1}\frac{Y_2}{w_P}.$$

The expressions in (30) state that the sign of the reaction of sectoral output with respect to changes in the price of pollution depend on the sectoral market shares in the factor markets, the demand elasticities and the Stolper-Samuelson derivatives. Regarding the denominator in (30) it is easy to show that it has to be positive under the assumption that sector 2 is more capital intensive than sector 1.

Expressions (30a) and (30b) can only be opposite in sign if the term in the square brackets in the nominators of the respective expressions are of the same sign.

If the two sector's factor demand for labor and capital are sufficiently similar in size, i.e. $s_L^1 \approx s_L^2$, and $s_K^1 \approx s_K^2$, then the reactions of sectoral output are always opposite in sign. Otherwise, it is possible that the reactions of sectoral output are equal or opposite in sign.