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## Exogenous spillover coefficients in economics: Case of reciprocal pollution

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**Wirtschaftswissenschaftliche Fakultät  
der Eberhard-Karls-Universität Tübingen**

**Exogenous Spillover Coefficients  
in Economics: The  
Case of Reciprocal Pollution**

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Indicators based on spillover coefficients contribute to the characterization of reciprocal externality fields. Such indicators can describe both quantity and structure aspects of diffusion schemes. In this paper the significance of spillover coefficients and corresponding indicators for bilateral externality coordination is demonstrated. Among other things, their relevance in instrumental designing is analysed. Finally "extended" spillover coefficients are derived, including damage aspects of external effects in addition to diffusion phenomena.

*Keywords:* external effects, externality indicators, pollutant diffusion, damage costs, policy coordination, emission taxes, air pollution, water pollution.

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# Exogenous Spillover Coefficients in Economics: The Case of Reciprocal Pollution\*

In economics external effects between economic subjects play an important role. Such externalities caused by economic activity influence the welfare of third parties without being compensated by market transactions.<sup>1</sup> This paper refers to the case of reciprocal externalities underlying a situation of bilateral environment pollution because the basic analytical facts can be illustrated best within this framework. Nevertheless, the results of the paper are also valid for analogous externality scenarios outside environmental policy. The analysis deals with the economic relevance of those determinants of reciprocal externality fields which are exogenous for the agents and can be expressed in the form of spillover coefficients.<sup>2</sup>

## 1. Introduction

By assumption the externality phenomenon results in the welfare function of the countries. The welfare of country  $i$  is defined by the function  $W_i = B_i(e_i) - D_i(g_i)$ . It depends on the national income whose production generates the emission of pollutants. The (gross)benefit  $B_i$  from income can be modelled as a function of the national emissions level ( $e_i$ ). The marginal productivity of the "factor" pollutant emission decreases with the input level:  $B'_i(e_i) > 0$ ,  $B''_i(e_i) < 0$ . The emission of pollutants does, however, not only imply the production of income, but also causes physical environmental damages. After monetary evaluation, these environmental damages enter into the welfare function as damage costs ( $D_i$ ). These are not directly based on the emissions level. Rather the basis is the so-called domestic pollutant deposition ( $g_i$ ). The damage costs are convex in the deposition level:  $D'_i(g_i) > 0$ ,  $D''_i(g_i) > 0$ . The national deposition depends on both domestic and foreign emission activity. The latter leads to the interstate externality relation which is the starting point of the modelling. Assuming that ecological interconnection between the countries is characterized by reciprocal (not unilateral) externalities, the present situation can be described by the following system of deposition functions, with the vector of  $a_{ij}$ -coefficients completely covering the spatial diffusion scheme of the pollutants:

$$\begin{aligned}g_1(e_1, e_2) &= a_{11}e_1 + a_{12}e_2, \\g_2(e_1, e_2) &= a_{21}e_1 + a_{22}e_2,\end{aligned}$$

with  $a_{11} + a_{21} = a_{12} + a_{22} = 1$ . The deposition level of country 1 ( $g_1$ ), and therefore the damage costs ( $D_1$ ) as well, are dependent on domestic and foreign emissions ( $e_1$  and  $e_2$ , respectively) according to the relevant diffusion coefficients  $a_{ij}$ . A linear correlation between emission and

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<sup>1</sup> An introduction to externality theory is provided in *Cornes/Sandler (1986)* and *Varian (1996)* for instance. For a critical assessment of the literature on external effects see *Richter/Wiegard (1993)*.

<sup>2</sup> For various aspects of transfrontier pollution see *Siebert (1985)*.

deposition is assumed. The size of internal and external effects depends on the level of the respective diffusion coefficients. Home coefficient ( $a_{ii}$ ) and export coefficient ( $a_{ji}$ ) of country  $i$  add up to one. The home coefficient of one country always represents the foreign coefficients of the other country. Analogously, the export coefficient of one country is the import coefficient of the other one.

## 2. Indicators based on spillover coefficients

The present externality field can be characterized by means of indicators which are divided into quantity and structural indicators. In this paper only *exogenous* variables are taken into account. Endogenous variables, such as emission levels, are not considered for describing externality fields. First, *structural indicators* are derived which classify reciprocal externality relations with regard to asymmetry aspects (see Table 1).

| EXPORT-HOME-<br>SPACE                          | IMPORT-HOME<br>SPACE                              | EXPORT-IMPORT<br>SPACE                        |
|--|---|---|
| $a_{21} > a_{11}$<br><i>external dominance</i> | $a_{12} > a_{11}$<br><i>control insufficiency</i> | $a_{21} > a_{12}$<br><i>export prevalence</i> |
| $a_{21} < a_{11}$<br><i>internal dominance</i> | $a_{12} < a_{11}$<br><i>control sufficiency</i>   | $a_{21} < a_{12}$<br><i>import prevalence</i> |

Tab. 1: Structural indicators based on spillover coefficients

In the following the analysis is conducted from country 1's point of view. Using the relation between export and home coefficient, country 1 is called "externally dominant" if the export coefficient exceeds the home coefficient ( $a_{21} > a_{11}$ ). This means, that country 1 externalizes the main "impact" of its emission activity. In the opposite case ( $a_{21} < a_{11}$ ), country 1 is characterized by "internal dominance". Within this framework one must take into account that the fixed correlation  $a_{21} = 1 - a_{11}$  holds. A second figure is based on the uncorrelated relation between import and home coefficient. It refers to the question as to what extent a country can control its deposition level through its own efforts and how intensive the dependence on external emission behavior is. In this context one can speak of a country's (relative) sufficiency and insufficiency, respectively, in controlling its domestic deposition level. Provided that the import coefficient of country 1 dominates its home coefficient ( $a_{12} > a_{11}$ ), country 1 is characterized by so-called (relative) "control insufficiency". If the coefficient relation is reversed, country 1 is regarded as (relatively) "control sufficient" ( $a_{12} < a_{11}$ ).<sup>3</sup> Further asymmetry characteristics can be expressed by means of the quota between export and import coefficients which are not correlated. For the case that country 1's export coefficient is higher than its import coefficient ( $a_{21} > a_{12}$ ) the country is called "export prevalent". Otherwise - if  $a_{21} < a_{12}$  holds - country 1 takes the position of "import prevalence".

Referring to potential interstate constellations, the following statements can be derived, partly based on the condition  $a_{11} + a_{21} = a_{12} + a_{22} (= 1)$ . First, because the export coefficient of one

<sup>3</sup> Regarding the problem of control (in)sufficiency in the case of so-called global pollutants see *Krumm (1996)*.

country represents the import coefficient of the other country, one country is export prevalent and the other one is import prevalent ("inverse constellation"), both to the same extent because of the relationship  $a_{21} - a_{12} = -(a_{12} - a_{21})$  which results from the condition above. Secondly, from this condition  $a_{21} - a_{22} = a_{12} - a_{11}$  follows. This means, that the difference between import and home coefficient must be the same for each country. Therefore the countries are either both "control sufficient" or both "control insufficient" ("identical constellation"). Thirdly, with respect to internal and external dominance, each interstate constellation is possible ("undetermined constellation"). Thus, the condition metioned above is not binding here.

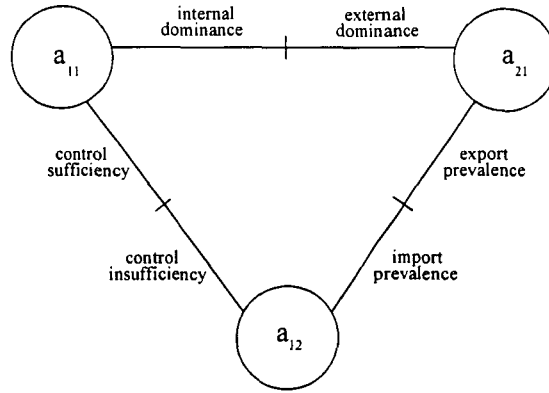


Fig. 1: Coefficient scheme

A second group of indicators reflects quantity aspects (so-called "*quantity indicators*", see Table 2). For this reason, new coefficients must be created using diffusion coefficients. In adding together home and import coefficients of a country one obtains the coefficient which determines the national deposition level. So one can speak of  $\gamma_i = a_{ii} + a_{ij}$  as the deposition coefficient of country i. Country 1 has a deposition surplus if  $\gamma_1 = a_{11} + a_{12} > 1$  holds, whereas if  $\gamma_1 < 1$  country 1 has a deposition deficit. Because of the relationship  $\gamma_1 - 2 = \gamma_2$  one country has a deposition surplus while the other realizes a deposition deficit of the same value. In the case that the size of bilateral externality intensity is of interest one can construct a transmission coefficient  $\lambda = a_{12} + a_{21}$  (with  $0 \leq \lambda \leq 2$ ). Because it results from the sum of the national export and import coefficients of a country (and the sum of the export coefficients of both countries, respectively) this coefficient is identical for both countries:  $\lambda = \lambda_1 = \lambda_2$ .<sup>4</sup>

| HOME-IMPORT-SPACE                                  | IMPORT-EXPORT-SPACE                                 |
|--|---|
| $a_{11} + a_{12} > 1$<br><i>deposition surplus</i> | $a_{12} + a_{21} > 1$<br><i>strong transmission</i> |
| $a_{11} + a_{12} < 1$<br><i>deposition deficit</i> | $a_{12} + a_{21} < 1$<br><i>weak transmission</i>   |

Tab. 2: Quantity indicators based on spillover coefficients

<sup>4</sup> A quantity indicator in the sense of an "emission coefficient" which would result from the sum of the home and the export coefficient ( $a_{ii} + a_{ji}$ ) is irrelevant, because this coefficient would always be one.

### 3. Spillover coefficients in the framework of quantity regimes

If both countries do not coordinate their externality-generating activities, a country determines its emission level in such a way that it maximizes the difference between gross emission benefit and deposition damage costs, assuming the emission level of the other country is given. For country 1, the optimization approach

$$(1) \quad \max_{e_1} \{B_1(e_1) - D_1(g_1)\} \quad \text{s.t.} \quad g = a \cdot e$$

holds, with the diffusion condition being formulated in matrix notation. Hence, the optimization condition

$$(2) \quad \frac{dB_1}{de_1} = a_{11} \frac{dD_1}{dg_1}$$

is relevant. Country 1 takes the marginal damage costs into consideration only to the extent of the home coefficient (the same holds for country 2). The external emission impact, however, is neglected. The resulting internalization deficit of the reciprocal externality field is the more distinct, the higher the transmission coefficient  $\lambda = a_{12} + a_{21}$  is, which includes the export coefficients of both countries. Using the residual relationship  $a_{ii} = 1 - a_{ji}$ , the noncooperation equilibrium of the countries is characterized by the condition

$$(3) \quad \frac{(D'_1 - B'_1) / D'_1}{(D'_2 - B'_2) / D'_2} = \frac{a_{21}}{a_{12}}.$$

The intensity of "export prevalence" of one country and the corresponding "import prevalence" of the other country, respectively (expressed in quotient  $a_{21}/a_{12}$ ), determines the interstate emission relation decisively.

If the countries coordinate their emission behavior, however, they maximize their common welfare by taking into consideration the external effects of their activity. Thus, they must solve the optimization problem

$$(4) \quad \max_{e_1, e_2} \{B_1(e_1) + B_2(e_2) - D_1(g_1) - D_2(g_2)\} \quad \text{s.t.} \quad g = a \cdot e.$$

In this case of common welfare maximization the following conditions result:

$$(5) \quad \frac{dB_1}{de_1} = a_{11} \frac{dD_1}{dg_1} + a_{21} \frac{dD_2}{dg_2} \quad \text{and} \quad \frac{dB_2}{de_2} = a_{12} \frac{dD_1}{dg_1} + a_{22} \frac{dD_2}{dg_2}.$$

Within this framework the external damages are completely taken into account. The additional damage costs to be considered are relatively high (low) if external dominance (internal dominance) is given. The optimal emission level of each country will always be lower than in the case of noncooperation, thus transition from noncooperation to "full cooperation" leads to the implementation of emission abatement measures.

The inclusion of the respective foreign welfare function implies high information requirements for both countries.<sup>5</sup> For this reason they may try to realize a less complicated regime, reducing the degree of information asymmetry involved. Therefore it is assumed that in a first negotiation step the countries came to an understanding on a distinct interstate emission quota  $\pi_1 = e_2 / e_1 (= \pi_2^{-1})$ , so that they must now - in the second negotiation step - agree on concrete emission levels  $e_1$  and  $e_2$  that are compatible with the negotiated quota.<sup>6</sup> In this case country 1 can determine its preferred level of emission rights  $e_1$  (and thereby  $e_2 = \pi_1 e_1$ ) by optimizing the welfare function

$$(6) \quad \max_{e_1} \{ B_1(e_1) - D_1(a_{11}e_1 + a_{12}\pi_1 e_1) \}.$$

Thus, optimization conditions (7a) and (7b), respectively, can be derived for country 1:

$$(7a) \quad \frac{dB_1}{de_1} = (a_{11} + a_{12}\pi_1) \frac{dD_1}{dg_1} \quad (7b) \quad \frac{dB_1}{de_1} = \frac{dD_1}{dg_1} \quad \text{for } \pi_1 = \frac{a_{21}}{a_{12}}.$$

The r.h.s. of condition (7a) includes the following facts: a marginal increase in  $e_1$  ( $de_1$ ) - now interpreted as an enlargement of the preferred emission rights of the home country - would imply an increase in the deposition level,  $dg_1 = a_{11}de_1$ . Moreover, this induces additional emission rights for the foreign country ( $de_2 = \pi_1 de_1$ ), resulting in further deposition:  $dg_1 = a_{12}\pi_1 de_1$  (induced import). In contrast to the noncooperative situation, the domestic marginal damage costs are considered not only in accordance with the home coefficient, rather the import coefficient is also taken into account, to the extent of the relative emission rights  $\pi_1$ . The coordination-induced additional benefit to be considered in the optimization is higher, the more intensive "insufficiency" in controlling national deposition is, measured by the ratio  $a_{12}/a_{11}$ . In the case of a deposition surplus ( $\gamma_1 = a_{11} + a_{12} > 1$ ), and therefore high domestic impact of emission activity at home and abroad, its relevance is diminished by a quota of emission rights of  $\pi_1 < 1$  (meaning  $e_2 < e_1$ ).

<sup>5</sup> On the relevance of information asymmetries see *Kuhl (1987)*; referring to the special case of unilateral externalities compare *Buchholz/Haslbeck (1991/92)*.

<sup>6</sup> Selected game-theoretical approaches are provided by *Pethig (1982)*. Institutional aspects are discussed by *von Weizsäcker/Welsch (1991)*.



The case where the countries have fixed the emission rights quota  $\pi_1 (= \pi_2^{-1})$  according to the relation of import coefficients  $\pi_1 = a_{21} / a_{12} (= e_2 / e_1)$  seems to be of special interest. This implies that the country which is more sensitive with regard to external emission is compensated with greater emission rights. Provided that country 1 is "import prevalent" ( $a_{21} < a_{12}$ ), it receives more emission rights than country 2 ( $e_1 > e_2$ ). For this case, i.e. for  $\pi_1 = a_{21} / a_{12}$ , optimization condition (7a) simplifies to (7b). Within this framework, a situation is simulated where an interstate externality relationship does not exist at all. In this special scenario the spillover coefficients are absolutely irrelevant for the calculation of the national preferred quantities of emission rights.

#### 4. Spillover coefficients in the framework of fiscal regimes

The cooperation regimes analysed so far are based on pure quantity control (quantity regimes). Bilateral coordination of the emission activity can, however, be realized by a fiscal mechanism as well, for example a subsidy approach. The countries could agree to the reciprocal subsidizing of emission abatement  $q_i = e_i^0 - e_i$  ( $e_i^0$  being the laissez-faire emission level) and use spillover coefficients for differentiating the subsidy rate. For instance, the uniform base rate  $z$  could be weighted with the national export coefficients. This effective subsidy rate is based on the scope of externalizing domestic emission abatement (export subsidizing). The higher the positive external effect (the higher the export coefficient), the higher the effective subsidy rate ( $a_{21}z$  and  $a_{12}z$ , respectively) will be. In this case the optimization approach is

$$(8) \quad \max_{e_i} \left\{ B_1(e_1) - D_1(g_1) + z[a_{21}(e_1^0 - e_1) - a_{12}(e_2^0 - e_2)] \right\} \quad \text{s.t.} \quad g = a \cdot e.$$

The bilateral subsidy regime, therefore, implies the following condition for calculating country 1's optimal emission level:

$$(9) \quad \frac{dB_1}{de_1} = a_{11} \frac{dD_1}{dg_1} + a_{21}z.$$

In contrast to noncooperative optimization, the subsidy approach requires taking into account the (relevant) effective subsidy rate. If the base rate  $z$  coincidentally corresponds with foreign marginal deposition costs in the optimum, this approach is compatible with global welfare maximization. For the case that the following relation

$$(10) \quad \frac{e_2^0 - e_2}{e_1^0 - e_1} \equiv \frac{q_2}{q_1} < \frac{a_{21}}{a_{12}}$$

between abatement quota and coefficient quota holds, country 1 is fiscal net profiteur of the subsidy regime. The chances for realizing such a position depends on whether country 1 is export or import prevalent (quotient  $a_{21}/a_{12}$ ).

Instead of using a subsidy approach, the countries could implement a bilateral tax system. Then the governments would have to pay a tax to a common environment agency corresponding to their national emission level. The tax revenues would be reimbursed to the countries in accordance with the agreed national redistribution parameter  $\beta_i$  ( $\sum_i \beta_i = 1$ ). For differentiating the gross tax rate the national export coefficients could be used. Thus, the part of the emissions which induces negative effects abroad would be covered by the tax (export taxation).<sup>7</sup> With the gross tax term defined as  $T_i = t \cdot a_{21}e_i$  the optimization calculus

$$(11) \quad \max_{e_i} \{B_i(e_i) - D_i(g_i) - ta_{21}e_i + \beta_i t(a_{21}e_i + a_{12}e_2)\} \quad \text{s.t.} \quad g = a \cdot e$$

holds. As a result, condition (12) becomes relevant for the determination of the optimal emission level:

$$(12) \quad \frac{dB_i}{de_i} = a_{11} \frac{dD_i}{dg_i} + a_{21}(1 - \beta_i)t.$$

The regime-specific additional abatement benefit is the higher, the higher the export coefficient of the concerned countries is. The solution would be globally welfare maximizing if the net tax rate  $(1 - \beta_i)t$  reflects the marginal deposition costs of the foreign country. Country 1 takes the position of a fiscal net profiteur of the tax system if the redistribution relation exceeds the quota of taxable emissions,  $(\beta_1/\beta_2) > (a_{21}e_1/a_{12}e_2)$ , with the term "taxable emissions" referring to the emission export which is liable to the tax. Provided that country 1 is "export prevalent", this means that  $(a_{21}/a_{12}) > 1$ , it can only be a fiscal net gainer of the system if the redistribution relation  $\beta_1/\beta_2$  is sufficiently higher than the emission quota  $e_1/e_2$  (in order to overcompensate the exogenous asymmetry proportion  $a_{21}/a_{12}$ ). The condition for the net profiteur position of country 1 can also be formulated referring to the constellations of spillover coefficients which determine export and import prevalence, respectively:

$$(13) \quad \frac{(1 - \beta_2)e_2}{(1 - \beta_1)e_1} > \frac{a_{21}}{a_{12}}.$$

In this case the import coefficient quota must be compared with the quota of weighted emissions, where the national net tax coefficients  $(1 - \beta_i)$  function as weight factors.

<sup>7</sup> Another approach for modelling an "emission export tax" assumes the redistribution of tax revenues to be based on lump-sum transfers, see *Mäler (1994)*, pp. 365.

The interstate differentiation according to the spillover coefficients must not be implemented within the framework of the tax rate scheme. An alternative would be to use the redistribution system. If this is done, the proportion of national import coefficients might become relevant:  $\beta_1 / \beta_2 = a_{12} / a_{21}$ .<sup>8</sup> Because of the necessity  $\sum_i \beta_i = 1$ , the transmission coefficient  $\lambda = a_{12} + a_{21}$  must be included as a standardizing factor. Thus, national redistribution parameters  $\beta_i = a_{ij} / \lambda$  result in the optimization problem

$$(14) \quad \max_{e_1} \{B_1(e_1) - D_1(g_1) - t e_1 + (a_{12} / \lambda) \cdot t(e_1 + e_2)\} \quad \text{s.t.} \quad g = a \cdot e.$$

Within this taxation regime, the emission quantity of country 1 must fulfill the condition

$$(15) \quad \frac{dB_1}{de_1} = a_{11} \frac{dD_1}{dg_1} + [1 - (a_{12} / \lambda)] t \quad \text{with} \quad \lambda = a_{12} + a_{21}.$$

Compared with noncooperation, the induced emission abatement will be the higher, the lower the import coefficient of the corresponding country is, because then the net tax rate (gross tax rate minus redistribution rate) would be higher. In the case of a "medium" transmission coefficient (that means  $\lambda = 1$ ), the marginal tax term simplifies to  $(1 - a_{12})t$  and  $a_{22}t$ , respectively. Thus, in condition (15) the weight factors of home and foreign coefficients appear.

### 5. Spillover coefficients in the context of "external integration"

In the following two concepts will be discussed which explicitly include foreign "aspects", but do not use interstate coordination instruments (as presented in the previous sections). In the first scenario, it is assumed that the countries realize a welfare loss, not only in the case of domestic but also in the case of foreign deposition. This implies the optimization problem

$$(16) \quad \max_{e_1} \{B_1(e_1) - D_1(g_1, g_2)\} \quad \text{s.t.} \quad g = a \cdot e$$

for country 1, with  $D_1'(g_2) > 0$  und  $D_1''(g_2) < 0$ . Hence, in calculating the optimal emission level, country 1 must take the following condition into account:

$$(17) \quad \frac{dB_1}{de_1} = a_{11} \frac{\partial D_1}{\partial g_1} + a_{21} \frac{\partial D_1}{\partial g_2}.$$

The consideration of external deposition effects is not instrument-induced, but rather preference-determined. A trade-off exists between the inclusion of both damage cost components, because home and export coefficients are negatively correlated. This scenario

<sup>8</sup> An alternative would be to use the quota of national deposition coefficients.

differs from the condition of global welfare maximization to that extent that not the foreign, but the domestic marginal damage cost is taken into account (resulting from an increase of external deposition).

In a second scenario, the countries could examine the option of implementing and financing emission abatement measures abroad, respectively, in order to influence domestic deposition from outside. One can speak of "External Implementation" (EI) of emission abatement in this case.<sup>9</sup> In this context it seems adequate to formulate the externality scheme from the viewpoint of abatement activity:  $r=a \cdot q$ , with  $r$  being the deposition decrease and  $q$  the emission abatement. Using this relationship,  $U_i(r_i)$  defines the benefit from domestic deposition decrease, and  $C_i(q_i)$  denotes the costs of emission abatement. The corresponding cost scheme of country  $i$  for the case of external implementation can be expressed by means of the transfer cost function  $F_i(q_{j,EI})$ .<sup>10</sup> Thus, country 1 faces the following problem in determining its optimal activity at home ( $q_1$ ) and abroad ( $q_{2,EI}$ ):

$$(18) \quad \max_{q_1, q_{2,EI}} \left\{ U_1[a_{11}(q_1 + q_{1,EI}) + a_{12}(q_2 + q_{2,EI})] - C_1(q_1) - F_1(q_{2,EI}) \right\} \quad \text{s.t.} \quad r = a \cdot q$$

Country 1 must, therefore, take into account the conditions (19a) and (19b) in order to calculate the optimal interstate allocation of its emission abatement effort:

$$(19a) \quad \frac{dC_1}{dq_1} = a_{11} \frac{dU_1}{dr_1} \quad \text{and} \quad (19b) \quad \frac{dF_1}{dq_{2,EI}} = a_{12} \frac{dU_1}{dr_1}.$$

This implies that in the optimum the national marginal benefit of decreasing domestic deposition must correspond with the weighted marginal costs of the alternative implementation forms. The weight factors to be considered are the inverse values of the "relevant" diffusion coefficients, meaning the home and the import coefficient, respectively. Combining (19a) and (19b) results in

$$(20) \quad \frac{dF_1/dq_{2,EI}}{dC_1/dq_1} = \frac{a_{12}}{a_{11}}.$$

The quotient of import and home coefficient determines the optimal proportion of internal and external implementation. Hence, the option "external implementation" is of special interest for country 1 if it has a high import coefficient and a low home coefficient. In this case of "control insufficiency" ( $a_{12}/a_{11} > 1$ ) the level of domestic deposition is more influenced by

<sup>9</sup> For an application of a similar concept in the case of "global pollutants" see *Cansier/Krumm (1996)*. Within that framework, External Implementation is only induced by interstate cost differences because bilateral asymmetries based on pollutant diffusion do not exist there.

<sup>10</sup> The costs of External Implementation are convex in domestic abatement effort realized abroad ( $F'_i > 0$ ,  $F''_i > 0$ ).

activities abroad than by corresponding measures at home. This exogenously determined preference in favour of external implementation (based on spillover coefficient values) can however be qualified if the costs of external implementation ( $F_1$ ) considerably exceed the costs of internal implementation ( $C_1$ ).

## 6. The concept of "extended" spillover coefficients

The spillover coefficients (narrowly defined) used so far reflect the emissions' impact on domestic and foreign deposition. In this section the concept of spillover coefficients shall be enlarged. For this reason the damages costs will be "split". In dividing the damage costs  $D_i(g_i)$ , two components are created: first, the damage costs as a function of the physical damages,  $D_i(s_i)$ , and second, the physical damages due to the deposition level,  $s_i(g_i)$ .<sup>11</sup> In marginal terms one obtains

$$(21) \quad \frac{dD_i}{dg_i} = \frac{dD_i}{ds_i} \cdot \frac{ds_i}{dg_i}.$$

With regard to aspects of information economics the following characterization can be made: the component  $D_i(s_i)$  reflects a *subjective* variable which cannot be verified by the other country because it is based on a domestic valuation process. In contrast, component  $s_i(g_i)$  is an *objective* variable since the concrete level of physical damages are intestately better observable. For this reason the  $s_i$ - $g_i$ -relation can be used for the coordination of bilateral externality activity, especially for the designing of instrumental parameters. In order to make instrumental use as simple as possible, and therefore relevant for practice, it seems reasonable to use an average value representing  $ds_i/dg_i$ . Thus, it is assumed that a marginal change of deposition always induces the same ecological impact, the average value however usually being differentiated between countries (according to differences in physical sensitivity of the national ecosystems). Given  $ds_i/dg_i = \sigma_i = \text{const.}$ , one can speak of  $\sigma_i$  as the damage coefficient. Combining the damage coefficient  $\sigma_i$  and an "accompanying" diffusion coefficient  $\alpha_{ij}$  (a so-called "*sigma-extension*") results in the "extended spillover coefficients":

$$(22) \quad \sigma_i \cdot \alpha_{ij} = \frac{ds_i}{dg_i} \cdot \frac{dg_i}{de_j},$$

This denotes the change of *linearized* physical damages based on a marginal change of emissions. Hence, the externality field can be expressed approximately in terms of "linearized physical damages":

$$\begin{aligned} s_1(e_1, e_2) &= \sigma_1 a_{11} e_1 + \sigma_1 a_{12} e_2, \\ s_2(e_1, e_2) &= \sigma_2 a_{21} e_1 + \sigma_2 a_{22} e_2, \end{aligned}$$

in matrix notation  $s = a \cdot e$ .

<sup>11</sup> Assuming that  $D'_i(s_i) > 0$  and  $D''_i(s_i) < 0$ .

Within this framework, "extended indicators" can be derived (see Table 3). Comparing these ones with the "ordinary" structural indicators (in a narrow sense) the following facts become clear:<sup>12</sup> first, a country which is "internally dominant in a narrow sense" can be "externally dominant in a broader sense", if an overcompensation takes place based on the cost component. Second, an import prevalent country in a narrow sense is able to "reach" the position of an export prevalent country in the broad sense, provided that a suitable cost constellation is given between home and abroad. Third, a country defined as an "exogenous loser country" according to the previous rules, implying a high import and a high home coefficient (low export coefficient) can - based on the new definition - "neutralize" this classification through a sufficiently low national damage coefficient (overcompensating the unfavourable constellation of diffusion coefficients).

| EXPORT-HOME-SPACE   | EXPORT-IMPORT-SPACE  |
|---|--|
| $\sigma_2 a_{21} > \sigma_1 a_{11}$<br><i>external dominance</i><br><i>(in a broad sense)</i> | $\sigma_2 a_{21} > \sigma_1 a_{12}$<br><i>export prevalence</i><br><i>(in a broad sense)</i> |
| $\sigma_2 a_{21} < \sigma_1 a_{11}$<br><i>internal dominance</i><br><i>(in a broad sense)</i> | $\sigma_2 a_{21} < \sigma_1 a_{12}$<br><i>import prevalence</i><br><i>(in a broad sense)</i> |

Tab. 3: Structural indicators based on spillover coefficients in a broad sense

In addition to these structural indicators, an extended quantity indicator can be derived as well. This is in the form of a "transmission coefficient in a broad sense", defined as the sum of linearized physical damages caused by external activities,  $\lambda^* = \sigma_1 a_{12} + \sigma_2 a_{21}$ . If this coefficient is high, a great internalization need is indicated, because of high export coefficients and/or high damage coefficients of the countries. Compared with this, internalization need defined so far was solely find out on the basis of high export coefficients.

## 7. On the relevance of spillover coefficients "in a broad sense"

The spillover coefficients in a broad sense can be used for the designing of coordination instruments. Therefore, a tax on "linearized" external physical damages (export damage taxation) can be levied in contrast to the "pure" export taxation discussed in section 4. The gross tax term of such a tax would be  $T_1 = t \cdot \sigma_2 a_{21} e_1$  (for country 1). Within this bilateral taxation framework, country 1 faces the optimization problem

$$(23) \quad \max_{e_1} \{ B_1(e_1) - D_1(g_1) - t \sigma_2 a_{21} e_1 + \beta_1 t (\sigma_2 a_{21} e_1 + \sigma_1 a_{12} e_2) \} \quad \text{s.t.} \quad g = a \cdot e.$$

This approach implies the following: first, country 1 includes its damage costs in the usual way, i.e. without underlying the simplification  $ds_i/dg_i = \sigma_i (= \text{const.})$ , because it is well-

<sup>12</sup> With regard to the categories "control sufficiency" and "control insufficiency" no extended indicator exists because the corresponding spillover coefficients would then be weighted with the *same* damage coefficient.

informed about the nonlinearity of its function  $s_1(g_1)$  and it is not willing to neglect the national evaluation component  $dD_1/ds_1$ . Secondly, the simplifying "sigma concept" becomes relevant only in so far as the foreign damage coefficient is part of the own effective tax rate. Hence, extended spillover coefficients play their role solely on the instrument level. Optimization approach (23) results in the condition

$$(24) \quad \frac{dB_1}{de_1} = a_{11} \frac{dD_1}{dg_1} + \sigma_2 a_{21} (1 - \beta_1) t.$$

In contrast to noncooperation, the marginal tax burden becomes relevant. The corresponding fiscal impacts are relatively strong if external dominance in a broad sense is given, because now (i.e. using the broader definition) the physical damage impact is included which has been neglected till now. When making this clear, one should note that the damage cost component  $a_{11}(dD_1/dg_1)$ , taken into account within the optimization condition, is approximately represented by  $\sigma_1 a_{11}(dD_1/ds_1)$ , so that - in principle - on the r.h.s. of condition (24) the weights  $\sigma_1 a_{11}$  and  $\sigma_2 a_{21}$  appear.

The interstate differentiation according to extended spillover coefficients must not necessarily use the tax rate. An alternative would be differentiating the redistribution parameter. If the reimbursement of the tax revenues is to be orientated on damage import, the redistribution quota  $\beta_1 / \beta_2 = \sigma_1 a_{12} / \sigma_2 a_{21}$  might be choosen. Assuming complete redistribution ( $\sum_i \beta_i = 1$ ), we obtain  $\beta_1 = \sigma_1 a_{12} / \lambda^*$  for country 1, with the "transmission coefficient in a broad sense",  $\lambda^* = \sigma_1 a_{12} + \sigma_2 a_{21}$ , taking on the function of a standardizing factor. Within this framework, country 1 determines its behavior according to the approach

$$(25) \quad \max_{e_1} \left\{ B_1(e_1) - D_1(g_1) - te_1 + (\sigma_1 a_{12} / \lambda^*) t(e_1 + e_2) \right\} \quad \text{s.t.} \quad g = a \cdot e.$$

Thus, the optimization condition of country 1 for calculating its emission quantity would be

$$(26) \quad \frac{dB_1}{de_1} = a_{11} \frac{dD_1}{dg_1} + \left[ 1 - (\sigma_1 a_{12} / \lambda^*) \right] t \quad \text{with} \quad \lambda^* = \sigma_1 a_{12} + \sigma_2 a_{21}.$$

The included marginal tax term turns to be higher in the case of "import prevalence in a broad sense" compared with corresponding export prevalence because in the first case the national redistribution parameter being considered is an above average value so that the relevance of taxation is diminished.

## 8. Summary

The present analysis has shown that exogenous spillover coefficients can contribute to the characterization of reciprocal externality relationships. Such coefficients and corresponding indicators aiming at diffusion phenomena reflect quantity and structure aspects of externality fields. While in the first case questions of internalization need are concerned, in the second case problems of interstate asymmetry are dealt with. In this paper the relevance of spillover coefficients for regime-specific optimization behavior is demonstrated. In addition their application in instrument design is discussed. The spillover coefficients (in a narrow sense) which aim at diffusion phenomena, i.e. at spatial effectiveness of external effects, can be extended ("sigma extension") in order to include the damage relevance of externalities. These spillover coefficients "in a broader sense" can be used in instrument design as well. The results of the analysis had been derived within the framework of bilateral pollution. However, they are also valid in the case of other forms of reciprocal external effects, provided that the corresponding externalities have an identical structure with respect to diffusion relations and benefit-cost-schemes.

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