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Regional aspects of environmental allocation

Zeitschrift für die gesamte Staatswissenschaft

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Suggested Citation: Siebert, Horst (1975) : Regional aspects of environmental allocation, Zeitschrift für die gesamte Staatswissenschaft, ISSN 0044-2550, Mohr, Tübingen, Vol. 131, Iss. 3, pp. 496-513

This Version is available at:

<https://hdl.handle.net/10419/3585>

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Regional Aspects of Environmental Allocation*

by
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This paper analyzes the problem whether effluent charges in the production sector should be regionally differentiated or applied nationally uniform. It attempts to specify some conditions that necessitate the regional differentiation of charges and it indicates some factors that influence the level of regional charges.

Section I presents the assumptions of the model. Specifically, the interregional diffusion of pollutants is taken into consideration. Section II derives the implications for the regional effluent charges if a national agency maximizes welfare for a two-region system. Section III addresses the problem raised in the debate by *Stein* [17] and by *Peltzman* and *Tiedeman* [11] whether, if charges should be regionally differentiated, this should be done by local authorities or a national agency. It is shown that letting independent local authorities set effluent charges is likely to lead to sub-optimization. Section IV analyzes the case that policy makers do not accept the outcome of market processes with respect to the interregional distribution of environmental quality and introduce the restraint of identical environmental qualities among regions because of equity considerations. Section V discusses a regionally differentiated standard price approach. The effect of these restraints on the effluent charges is studied. Finally, section VI indicates possible extensions of the model.

I. The Model

Assume a two-region-two-sector-model with superscript $j = 1, 2$ indicating regions and subscript $i = 1, 2$ denoting sectors. Assume regional welfare W^j is determined by the output vector (Q^j_1, Q^j_2) and regional environmental quality U^j .

$$(1.1) \quad W^j = W^j(Q^j_1, Q^j_2, U^j)$$

The production function is given by

$$(1.2) \quad \begin{aligned} Q^j_i &= F^j_i(R^j_i, S^j) \\ \text{with } F^j_{iR} &> 0, F^j_{iRR} < 0 \\ \text{and } F^j_{iS} &< 0, F^j_{iSS} > 0 \end{aligned}$$

* This article has developed from a paper [15a] written for the OECD. I acknowledge comments from *Michel Potier*.

where R^j_i denotes resource R being used in sector i of region j and S^j indicates the quantity of pollutants ambient in region j .

For simplicity, production generates a single pollutant S . Pollution generation is described by

$$(1.3) \quad S^j_i = H^j_i(Q^j_i) \text{ with } H^j_i' > 0, H^j_i'' \geq 0$$

Engineering production functions suggest for a set of production procedures (e.g. engines) that output can be increased only with progressively rising inputs (e.g. fuels). Progressively increasing inputs, however, may very well explain $H^j_i'' > 0$. Conceivably, in other cases pollutants are in a constant relation to output for a given production procedure, so that $H^j_i'' = 0$. The case that the marginal tendency to pollute will decline, $H^j_i'' < 0$, is ruled out in the following analysis.

Pollutants emitted S^j_e are defined as

$$(1.4) \quad S^j_e = H^j_1(Q^j_1) + H^j_2(Q^j_2)$$

Pollutants ambient in the regional environment (S^j) are defined by pollutants emitted (S^j_e) plus the net import of pollutants from other regions (S^{jM}) minus pollutants abated by the environmental protection agency (S^j_r) and pollutants degraded by the environment \bar{S}^j_a .

The assimilative capacity of the environment (\bar{S}^j_a) is given¹; pollutants accumulated over time are not considered. Assume for simplicity that interregional environmental interdependencies are such that pollutants are exported from region 2 to region 1 through environmental media (one-way interregional pollution). Then the quantity of pollutants ambient in region 1 is given by

$$(1.5) \quad S^1 = S^1_e + S^{21}_M - S^1_r - \bar{S}^1_a$$

The quantity of pollutants² in region 2 is given by

$$(1.6) \quad S^2 = S^2_e - S^{21}_M - S^2_r - \bar{S}^2_a$$

It is assumed that pollutants exported from region 2 to region 1 are a constant fraction α^{21} of pollutants emitted in region 2

$$(1.7) \quad S^{21}_M = \alpha^{21} S^2_e$$

Environmental quality U^j is determined by the quantity of pollutants ambient in the environment

$$(1.8) \quad U^j = g^j(S^j) \text{ with } g^j' < 0, g^j'' < 0$$

¹ In some cases it may be more realistic to assume that the assimilative capacity is given as a constant fraction of the concentration of the pollutants, compare f. i. the steady state solution to the Streeter-Phelps equations.

² In order to ensure that S^j in (1.5) and (1.6) will not become negative for S^j_e , $S^{21}_M = 0$, a slack variable can be introduced into these definitions.

The environmental protection agency uses resource R for reducing the quantity of pollutants

$$(1.9) \quad S^j_r = F^j_3(R^j_3) \text{ with } F^j_{R3} > 0, F^j_{RR3} < 0$$

The quantity of resources \bar{R} in the two-region-system is given

$$(1.10) \quad \bar{R} = \sum_j \sum_i R^j_i + \sum_j R^j_3$$

II. Regional Implications of Maximizing National Welfare

Assume that a national environmental policy agency maximizes total welfare of the two-region-system and that the welfare of the nation is the sum of the two regional welfare functions³. The Lagrangean expression is

$$\begin{aligned} L = & \sum W^j(Q^j_1, Q^j_2, U^j) \\ & + \sum_j \sum_i \lambda^j_i [F^j_i(R^j_i, S^j) - Q^j_i] \\ & + \lambda_3 [\bar{R} - \sum_j \sum_i R^j_i - \sum_j R^j_3] \\ & + \sum \lambda^j_4 [F^j_3(R^j_3) - S^j_r] \\ (2.1) \quad & + \sum \lambda^j_5 [g^j(S^j) - U^j] \\ & + \lambda^1_6 [S^1 - S^1_e - S^{21}_M + S^1_r + \bar{S}^1_a] \\ & + \lambda^2_6 [S^2 - S^2_e + S^{21}_M + S^2_r + \bar{S}^2_a] \\ & + \sum \lambda^j_7 [\sum_i H^j_i(Q^j_i) - S^j_e] \\ & + \lambda_8 [S^{21}_M - \alpha^{21} S^2_e] \end{aligned}$$

The first-order conditions⁴ are:

$$\begin{aligned} \left\{ \begin{array}{l} \frac{\partial L}{\partial Q^j_i} = 0: \quad \lambda^j_i - H^{j'}_i \lambda^j_7 = \frac{\partial W^j}{\partial Q^j_i} \\ \frac{\partial L}{\partial U^j} = 0: \quad \lambda^j_5 = \frac{\partial W^j}{\partial U^j} \\ \frac{\partial L}{\partial S^j} = 0: \quad -\lambda^j_1 F^j_{is} - \lambda^j_2 F^j_{2s} - \lambda^j_5 g^{j'} = \lambda^j_6 \\ \frac{\partial L}{\partial R^j_i} = 0: \quad \lambda^j_i F^j_{iR} = \lambda_3 \end{array} \right. \end{aligned} \quad \begin{array}{l} (i) \\ (ii) \\ (iii) \\ (iv) \end{array}$$

³ It is assumed that the welfare function is separable. This implies that $\partial W / \partial U$ is independent of the level of private goods, and that $\partial W / \partial Q^j_i$ is independent of the level of U . Also it is assumed that welfare in region 1 does not depend on variables in region 2.

⁴ The conditions with respect to the multipliers are not written out. Conditions (2.2) are necessary, but not sufficient. Second order conditions are not analyzed.

$$(2.2) \quad \left\{ \begin{array}{ll} \frac{\partial L}{\partial R^j_3} = 0: & \lambda_4 F^j_{R3} = \lambda_3 \quad (\text{v}) \\ \frac{\partial L}{\partial S^j_r} = 0: & \lambda_4 = \lambda_6 \quad (\text{vi}) \\ \frac{\partial L}{\partial S^1_e} = 0: & \lambda^1_6 = -\lambda^1_7 \quad (\text{vii}) \\ \frac{\partial L}{\partial S^2_e} = 0: & \lambda^2_6 = -\lambda^2_7 - \lambda_8 \alpha^{21} \quad (\text{viii}) \\ \frac{\partial L}{\partial S^{21}_M} = 0: & -\lambda^1_6 + \lambda^2_6 + \lambda_8 = 0 \quad (\text{ix}) \end{array} \right.$$

Eq. (2.2) specifies the shadow prices for the two-region system with $\lambda_i \geq 0$ indicating the scarcity price of commodities, $\lambda_3 \geq 0$ of resource R , $\lambda_5 \geq 0$ of the environment, $\lambda_4 \geq 0$ of pollutants abated, $\lambda_6 \geq 0$ of regional assimilative capacities, $\lambda_7 \leq 0$ of emissions and λ_8 for the pollutants exported.

1. Implications for Effluent Charges

From (i), (ii), (iii) and (vii) in (2.2) we obtain for the shadow price of pollutants emitted in region 1

$$(2.3) \quad \lambda^1_7 = \frac{g^{1'} \frac{\partial W^1}{\partial U^1} + \sum_i F^1_{is} \frac{\partial W^1}{\partial Q^1_i}}{1 - \sum_i H^{1'}_i F^1_{is}}$$

The shadow price of pollutants is determined by

- environmental damage of the pollutants. Environmental damage is defined by marginal social damage expressed in physical terms $\left(g' = \frac{\partial U}{\partial S}\right)$ and by the evaluation of one unit of the environment $\left(\frac{\partial W}{\partial U}\right)$
- damage of the pollutant caused in activities 1 and 2. Damage in production is expressed by the effect of one unit of pollutant on sector output (F_{is}) and by the evaluation of the product affected $\left(\frac{\partial W}{\partial Q_i}\right)$.
- the expression $(\sum H_i F_{is})$ in the denominator accounting for the fact that one unit of pollutants ambient in the environment affects production negatively and that consequently emissions are partly reduced. The higher the indirect effect of immissions on emissions, the more will the effluent charge be reduced absolutely.

For region 2 we have

$$(2.4) \quad \lambda^2_7 = \frac{g^{2'} \frac{\partial W^2}{\partial U^2} + \sum_i F^2_{is} \frac{\partial W^2}{\partial Q^2_i} - \alpha^{21} \lambda_8}{1 - \sum_i H^{2'}_i F^2_{is}}$$

From 2.2 (ix) and (iii) λ_8 is defined as

$$(2.5) \quad \lambda_8 = - \sum_i \lambda_i F^1_{is} - g^1 \frac{\partial W^1}{\partial U^1} + \sum_i \lambda^2_i F^2_{is} + g^2 \frac{\partial W^2}{\partial U^2}$$

$\lambda_8 > 0$, if in the optimum the damage caused by one unit of pollutants is higher in region 1 than in region 2. $\lambda_8 < 0$, if marginal damage is smaller in region 1 than in 2. λ_8 consequently accounts for a difference in social damage of a unit of pollutants in the two regions. It can be interpreted as a shadow price for pollutants exported. (2.4) shows that the effluent charge in region 2 includes differential damage caused by the exports of pollutants.

The condition that the effluent charge should be set so that marginal abatement costs equal prevented marginal social damage now accounts for differential damage. From (v), (vi), (vii) and (viii) in (2.2)

$$(2.6) \quad -\lambda^1_7 = \frac{\lambda_3}{F^1_{R3}} \quad \text{and} \quad -\lambda^2_7 = \frac{\lambda_3}{F^2_{R3}} + \lambda_8 \alpha^{21}$$

Since λ_3 denotes the shadow price of the resource \bar{R} , λ_3/F^j_{R3} represents marginal pollution abatement costs.

For region 1 the effluent charge should be levied so that from (2.3, iii) and (2.6)

$$(2.7) \quad -\lambda^1_7 = \lambda_3/F^1_{R3} = \frac{-g^1 \frac{\partial W^1}{\partial U^1} - \sum_i F^1_{is} \frac{\partial W^1}{\partial Q^1_i}}{1 - \sum_i H^1_i F^1_{is}}$$

or that marginal costs of abatement and prevented marginal social damage are equalized. Observe that although $\lambda_8 \alpha^{21}$ is not contained in 2.7, the import of pollutants increases S^1 and the derivatives in 2.7 increase absolutely with S^1 .

For region 2 the effluent charge is

$$(2.8) \quad -\lambda^2_7 = \frac{\lambda_3}{F^2_{R3}} + \alpha^{21} \lambda_8 = \frac{-g^2 \frac{\partial W^2}{\partial U^2} - \sum_i F^2_{is} \frac{\partial W^2}{\partial U^2_i} + \alpha^{21} \lambda_8}{1 - \sum_i H_i F_{is}}$$

(2.8) indicates that effluent charges should not only equalize marginal abatement costs and prevented marginal damage but should account for the differential damage of a unit of pollutant exported to region 1.

2. Implications for Commodity Prices

The interregional export of pollutants also affects the shadow price of commodities. For λ^2_i we have:

$$(2.9) \quad \lambda^2_i = \frac{\partial W^2}{\partial Q^2_i} + \frac{H^2_i \left[g^2 \frac{\partial W^2}{\partial U^2} + \sum_i F^2_{is} \frac{\partial W^2}{\partial Q^2_i} - \alpha^{21} \lambda_8 \right]}{1 - \sum_i H^2_i F^2_{is}}$$

The commodity price is determined by the marginal evaluation of the commodity minus the social damage caused by the pollutants generated by one unit of production ($H'_i > 0$), namely the damage caused to the environment $\left(g' \frac{\partial W}{\partial U}\right)$ and the damage caused as external diseconomies to activities 1 $\left(F_{is} \frac{\partial W}{\partial Q_i}\right)$ and 2, and differential damage caused by the export of pollutants. The evaluation of commodity i produced in region 2 is not only corrected for the social damage caused in region 2 but also for the social damage caused in region 1, if pollutants are diffused inter-regionally and if a difference in marginal damage in the two regions exists.

The expression for commodity i produced in region 1 is analogous to (2.9), it does, however, not contain the expression $\alpha^{21} \lambda_8$ under the assumptions made.

Eq. (2.9) shows that region 2 may obtain a "production incentive" in the case that marginal damage of a unit of pollutants exported is smaller in region 1 than in region 2. The interregional export of pollutants appears as one factor determining comparative advantage as long as $\lambda_8 < 0$.⁵

3. Short-run and Long-run Aspects

Effluent charges have to be differentiated regionally due to the following factors

- i) the interregional diffusion of pollutants if a differential damage exists, i. e. if $\lambda_8 \neq 0$. This follows from a comparison of (2.3) and (2.4);
- ii) difference in regional assimilative capacities. From (2.2 vii, viii), the negative effluent charge should be identical to the shadow price of the assimilative capacity, i. e. $\frac{\partial L}{\partial S'_a} = \lambda'_6$ and $\lambda'_6 = -\lambda'_7$ (if the interregional diffusion of pollutants is neglected). Different regional assimilative capacities such as a higher quantity of BOD available for the degradation of organic wastes in aquatic systems imply *ceteris paribus* regionally different effluent charges;

⁵ Other implications are more familiar. From (2.2 iv) it follows that the usual condition

$$\frac{\lambda_1}{\lambda_2} = \frac{F_{2R}}{F_{1R}}$$

still holds, i. e. the price relation of the two commodities is identical to the opposite relation of marginal factor productivities. Also the relation of commodity price and the price of pollutants abated are determined by the opposite relation of marginal productivities.

$$\frac{\lambda_1}{\lambda_4} = \frac{F_{R3}}{F_{R1}}$$

- iii) differences in the demand for assimilative services. The scarcity of assimilative capacity is not only determined by environmental endowment but also by the demand for assimilative services. Demand for assimilative services can be regarded as a function of economic activity and is generated both by production and consumption activities. Consequently, the demand for assimilative services of the environment also depends on such factors as the regional level of development, the rate of growth, technology used, industry mix and population agglomeration. In the model, only the demand for assimilative services of production activities is considered being expressed by the quantity of emissions. With emissions increasing, marginal damage will rise *ceteris paribus*;
- iv) the evaluation of one unit of the environment, $\partial W/\partial U$. This factor can be assumed to vary between regions with regional preferences and income per capita;
- v) differences in the marginal damage function between regions. This can be due to a higher population density causing a greater marginal damage in physical terms ($g^{1'} \neq g^{2'}$), a greater geographic density of industrial activities or a different industry mix ($F^1_{is} \neq F^2_{is}$) and different environmental conditions.

Regional differences in these factors require different effluent charges (or emission norms). *Ceteris paribus*, the effluent charge must be higher, the smaller the assimilative capacity of the environment, the higher the demand for assimilative services and the higher the evaluation of the environment for consumption purposes.

It has been argued that nationally uniform effluent charges should be applied because governments should not distort competition and because equal starting conditions for private production activities should be secured in a national market. This argument of harmonizing starting conditions in a market area playing an important role in European environmental policy cannot be accepted for the environmental issue. In the past, the environment has been treated as a free resource. Consequently, environmental scarcity did not influence regional price or location advantages. The use of the environment as a free commodity is, however, the basic reason for environmental disruption. It has long been recognized that the environment is scarce and that its use should either be regulated by a price system or controlled by allocating quantities to different (and competing) uses. It would be economically absurd, to try to harmonize these production and location advantages by charging identical effluent charges.

In deriving policy recommendations one has to specify whether the shadow prices relate to a long run or a short run optimum. In a long run optimum, i.e. over some decades, all possible reactions of the private sector such as the relocation of factors have taken place whereas in a short run optimum such reactions may not yet have occurred. Since the derivatives in (2.3) and (2.4) also depend on the level of the variables in the optimum, diverging conclusions on the regional application of envi-

ronmental policy instruments emerge from the two opposing frames of references [7, 11, 17, 18].

In the long run optimum, effluent charges will tend to equalize between regions by four different mechanisms: i) the transfer of pollutants for $\lambda_8 < 0$, ii) resource mobility, iii) population migration and iv) the interregional exchange of commodities [16a].

- i) Assume that in a short run optimum marginal damage is smaller in region 1 than in region 2, for instance because of a larger assimilative capacity in region 1 for a *ceteris paribus* in the other factors influencing the effluent charges. Then $\lambda_8 < 0$ ensures that because of the interregional diffusion of pollutants region 2 can use the assimilative capacity of region 1. In this case, $\lambda_8 < 0$ represents a built-in-incentive to export pollutants.

This incentive, however, is corrected in subsequent short-run optima, if more and more pollutants are exported. Observe, that with the export of pollutants marginal damage becomes smaller in region 2 since both $g^{2'}$ and $F^{2'is}$ can be expected to be smaller with less immissions. In the area importing the pollutants, however, the derivatives $g^{1'}$ and F^{1is} are higher with a larger quantity of immissions. Eventually, marginal damage in region 1 may be higher than damages prevented in region 2 by the export of pollutants. Consequently, λ_8 must be positive and the effluent charge has to be raised in region 2. As long as $\lambda_8 < 0$, λ_8 can be interpreted as making for a tendency to equalize concentrations of immissions in the two regions.

- ii) Consider the implications of a set of subsequent short run optima with respect to factor mobility.

Assume the environment is more scarce in region 1 than in region 2. Then the effluent charge has to be higher in region 1. This has two consequences:

- Since the price for pollutants abated will be higher in region 1, resources will move to pollution abatement processes and pollutants will be reduced in region 1. Pollution abatement will become more costly in region 2 and the effluent charge has to rise in region 2.
- According to Eq. (2.9), the shadow price for commodities produced in region 1 must be lower. For a given allocation of resources, according to (2.2 iv) the resource price must be lower. In the long run firms react by leaving the area⁶. Thus demand for assimilative services decreases and consequently the effluent charge in region 1 will fall; the charge has to rise in region 2.

- iii) Alternatively, the migration of people will in the long run tend to equalize effluent charges. If migration depends on environmental quality [13], people will migrate to the area with better environmental quality, increasing the demand for environmental consump-

⁶ Assume for instance that relocation costs are zero whereas abatement costs are positive.

tion goods in region 2. An increase in demand implies a higher social damage of one unit of pollutants, and effluent charges must rise in region 2. In region 1, however, the demand for the environment as a consumption good decreases and the effluent charge falls. Consequently migration leads to the equalization of regional charges.

- iv) If both labor and capital mobility are considered, a tendency to equalize effluent charges will also exist. Region 2 will attract labor with the consequence that the evaluation of the environment is increased, and it also may attract capital, thus increasing the quantity of pollutants emitted and consequently marginal social damage. From both effects, the effluent charge must rise.
- v) Even if resources are completely immobile interregionally, commodity trade will make for an equalization of effluent charges in the long run under specific conditions such as identical production functions in the two regions. Region 1 specializes in the production of commodities with lower pollution generation exporting pollution via trade. The region richly endowed with environmental capacity specializes in the production of commodities with a higher pollution generation [10, 12]. The factor price equalization theorem will also hold for the environment as an input to production processes [16a].

It can be expected that environmental policy has to take into account the temporary interregional immobility of factors and commodities and consequently will be oriented towards short run optima. In order to reach those short run optima regionally differentiated effluent charges are required. Over a series of subsequent short run optima regional effluent charges will tend to approach each other.

III. Regional vs. National Authorities

If environmental policy instruments are to be differentiated regionally, the institutional problem arises whether the application of environmental policy instruments should be conferred upon independent regional authorities. Since regional authorities may be especially appealing for countries with a federal political structure the problem of regional vs. national authorities is of considerable practical importance.

In favor of regional authorities, the argument has been put forward that regional authorities are closer to the problem and that consequently they are better informed than national agencies, i.e. that time-lags in the data gathering process are shorter⁷ and that regional agencies are better able to evaluate environmental damage⁸. On the other hand,

⁷ These information advantages become partly less important with the nation-wide implementation of automatic monitoring devices.

⁸ With respect to this argument, two different types of agencies should be distinguished. If the agency is a purely administrative authority, it is difficult to imagine how an administrator can obtain the relevant information on individual preferences. It is evident that the evaluation advantage implies

regional authorities are under considerable economic pressure from local industry to lower effluent charges since the firms will otherwise locate in other areas [17]. Also regional authorities are not likely to take into consideration that regional welfare functions are interdependent, i.e. that the environment of an area may also be an input in the welfare function of inhabitants of the other area (as in the case of recreation areas for inhabitants of nearby agglomerations).

A specific problem arises from the definition of the region. A region is defined in terms of environmental interdependence with respect to one specific medium of the environment. Since environmental media differ in spatial extent, i.e. since air fields are geographically different from river basins, environmental planning regions are different for different environmental media. Also emissions of pollutants into one medium can (at least partly) be substituted by emissions to another medium. For effective environmental resource management it is necessary to take these interdependencies into account. It can be expected that this co-ordination problem cannot be tackled by independent regional authorities, but that a national agency is better fit to deal with this question.

The model presented enables us to indicate one additional disadvantage of independent regional authorities, namely that they are not likely to take into consideration the export of pollutants generated in the region and being diffused to other areas. The export of pollutants does not affect the environmental quality of the area and the regional authority has no incentive to include exported pollutants in its calculation.

It can be assumed that regional authorities will maximize regional welfare. The maximization problem now consists in maximizing the two regional welfare functions separately for the respective regional constraints. Since the given resource \bar{R} is binding for both maximization problems either a mobility function for R must be introduced or R^j must be taken as given. This last assumption is made here.

The implication of separate regional maximization⁹ is that the effluent

the existence of a set of rules by which the agency obtains information on individual preferences and by which individual preferences are amalgamated into regional welfare functions. This, however, implies that the purely administrative agency has no evaluation advantage and that, if the agency is elected by the inhabitants of a region, electioneering must be considered as part of information costs.

⁹ For region 1 we have the following problem.

$$\begin{aligned}
 (1) \quad L^1 = & W^1(Q^1, Q^2, U^1) \\
 & + \sum \lambda^1_i [F^1_i(R^1_i, S^1) - Q^1_i] \\
 & + \lambda^1_3 [\bar{R}^1 - \sum R^1_i - R^1_3] \\
 & + \lambda^1_4 [F^1_3(R^1_3) - S^1_r] \\
 & + \lambda^1_5 [g^1(S^1) - U^1] \\
 & + \lambda^1_6 [S^1 - S^1_e - S^{21}_M + S^1_r + \bar{S}^1_a] \\
 & + \lambda^1_7 [\sum H^1_i(Q^1_i) - S^1_e]
 \end{aligned}$$

charge λ^1_7 is given by (2.3) and λ^2_7 by an expression analogous to (2.3) with variables of region 2. The interregional transfer of pollutants is no longer accounted for by the effluent charge. As another implication it follows that

$$(3.1) \quad \frac{\partial L^1}{\partial S^{21}_M} = -\lambda^1_6 \quad \text{and} \quad \frac{\partial L^1}{\partial S^1_a} = \lambda^1_6$$

whereas

$$(3.2) \quad \frac{\partial L^2}{\partial S^{21}_M} = \frac{\partial L^2}{\partial S^2_a} = \lambda^2_6$$

In region 1, the import of pollutants has the same effect as a reduction in assimilative capacity, whereas the authority of region 2 regards the export of pollutants as an augmentation of the regional assimilative capacity. Since part of the pollutants emitted in region 2 are exported to region 1 the pollutants ambient in region 2 are reduced. This leads to a lower environmental damage in region 2. Consequently, λ^2_6 is lower than it should be from efficiency considerations. In region 1, pollution, environmental damage and the effluent charge are too high. The shadow price of the pollutant does not reflect environmental scarcity in the two regions; the effluent charges are distorted.

Regional authorities lead to a non-optimal allocation of resources and the environment. Economic activity in region 2 is stimulated by letting region 1 carry the social costs arising from economic activities in region 2. This can also be seen by determining the shadow prices for the commodities in the two regions.

For region 2, the restriction with respect to λ^2_6 is given by

$$(2) \quad \lambda^2_6 [S^2 - S^2_e + S^{21}_M + S^e_r + \bar{S}^2_a]$$

For region 1 we have

$$\frac{\partial L^1}{\partial Q^1_i} = 0: \quad \lambda^1_i - \lambda^1_7 H^{1'}_i = \frac{\partial W^1}{\partial Q^1_i} \quad (i)$$

$$\frac{\partial L^1}{\partial U^1} = 0: \quad \lambda^1_5 = \frac{\partial W^1}{\partial U^1} \quad (ii)$$

$$\frac{\partial L^1}{\partial R^1_i} = 0: \quad \lambda^1_i F_{iR} = \lambda^1_3 \quad (iii)$$

$$(3) \quad \frac{\partial L^1}{\partial R^1_3} = 0: \quad \lambda^1_4 F_{R3} = \lambda^1_3 \quad (iv)$$

$$\frac{\partial L^1}{\partial S^1} = 0: \quad -\sum \lambda^1_i F^1_{iS} - \lambda^1_5 g^{1'} = \lambda^1_6 \quad (v)$$

$$\frac{\partial L^1}{\partial S^1_r} = 0: \quad \lambda^1_4 = \lambda^1_6 \quad (vi)$$

$$\frac{\partial L^1}{\partial S^1_e} = 0: \quad \lambda^1_6 = -\lambda^1_7 \quad (vii)$$

The shadow price of commodity i in region 2 is given by

$$(3.3) \quad \lambda_i^2 = \frac{\partial W^2}{\partial Q_i^2} + \frac{H_i^{2'} \left[g^{2'} \frac{\partial W^2}{\partial U^2} + \sum_i F_{is}^2 \frac{\partial W^2}{\partial Q_i^2} \right]}{\left[1 - \sum_i F_{is}^2 \frac{\partial W^2}{\partial Q_i^2} \right]}$$

Compare (3.3) to (2.9). Contrary to a national agency, a regional authority will not set effluent charges in such a way that the shadow price of a commodity is reduced by $\alpha^{21} \lambda_8$, namely the proportion of pollutants transferred to region 1 and differential damage λ_8 . Only if $\lambda_8 = 0$, the same environmental allocation will result. For $\lambda_8 < 0$, environmental allocation is sub-optimal since national welfare could be increased by exporting pollutants to region 1. For $\lambda_8 > 0$, environmental allocation is sub-optimal since region 2 does not consider the social costs of exporting pollutants.

One could argue that high costs of coordination and suboptimization in the case of independent local control can be avoided by limiting the export of pollutants to other areas by means of "regional export norms for pollutants". This argument, however, does not take into consideration that, granted the export of pollutants can be measured, this type of standard is unlike immission norms not likely to remain in effect for some time. Export norms for pollutants have to be changed similarly as λ_8 with regional emissions, industrial structure, and the evaluation of the environment due to alternations in the preference structure or population density in the two regions. For instance, population growth in the region importing pollutants leads to an increase of social damage for a given quantity of pollutants. This would necessitate a more strict standard for exports of pollutants from the polluting region. With independent regional authorities operating within the export constraint it may be extremely difficult politically, to change standards for these economic and social reasons and it may be easier for a national authority to adjust regional effluent charges that do not specifically relate to the exports of pollutants.

IV. Implications of Identical Regional Environmental Qualities

Maximization of the sum of the welfare of the two regions as assumed in section II may lead to the result that environmental quality differs between regions. Conceivably one region may have a better environmental quality and a lower material welfare whereas the other area may have a larger quantity of commodities and a lower environmental quality.

This result, ensuring maximum national welfare, may be in conflict with equity considerations if equity is interpreted with respect to the interregional distribution of welfare. A similar problem arises with respect to growth policy where maximizing the national growth rate [15]

may be restrained by preventing intolerable interregional differences in growth rates or income. Especially if environmental quality is managed by a national agency, restraints on interregional welfare differences may be politically demanded.

In the practical world, it can be expected that restraints are not formulated with respect to regional welfare but with respect to environmental quality, irrespective of the welfare gained (lost) from the increased (reduced) supply of private goods due to lower (better) environmental quality. Thus the constitution of FRG explicitly demands in articles 72 and 106 the uniformity of living conditions between regions. Assume such a policy is followed and the national environmental agency maximizes national welfare under the restriction that the two regions should have the same environmental quality. Then the additional restriction

$$(4.1) \quad \lambda_9 [U^1 - U^2]$$

is introduced into (2.1). (ii) in (2.2) is changed into

$$(4.2) \quad \begin{aligned} \lambda^1_5 &= \frac{\partial W^1}{\partial U^1} + \lambda_9 \\ \lambda^2_5 &= \frac{\partial W^2}{\partial U^2} - \lambda_9 \end{aligned}$$

The shadow price for one unit of the environment is no longer given by the contribution of one unit of the environment to regional welfare $\left(\frac{\partial W^j}{\partial U^j}\right)$, but is corrected by a factor λ_9 .

The shadow price for pollutants in region 1¹⁰ is given by

$$(4.3) \quad \lambda^1_7 = \frac{g^{1'} \frac{\partial W^1}{\partial U^1} + \sum F^{1'is} \frac{\partial W^1}{\partial Q^{1i}} + g^{1'} \lambda_9}{1 - \sum H^{1'i} F^{1'is}}$$

and the price for commodity 1 by

$$(4.4) \quad \lambda^1_i = \frac{\partial W^1}{\partial Q^{1i}} + \frac{H^{1'i} \left[g^{1'} \frac{\partial W^1}{\partial U^1} + \sum F^{1'is} \frac{\partial W^1}{\partial Q^{1i}} + g^{1'} \lambda_9 \right]}{1 - \sum H^{1'i} F^{1'is}}$$

Compared to section II, the effluent charges in the two regions must now be changed in order to account for the effect of one unit of pollutants on the fulfillment of restriction 4.1. Three cases have to be distinguished:

¹⁰ The expressions for λ^2_7 , λ^2_i are analogous with $g^2 \lambda_9$ having the opposite sign to (4.3) and (4.4).

- i) Let ${}^oU^j$ denote the optimal value of the maximization problem in (2.1) and assume that ${}^oU^1 > {}^oU^2$. Then the optimal solution is restricted by (4.1) in such a way that the optimal value ${}^oU^1$ must be reduced. Let $T = U^1 - U^2 = 0$ in the optimal solution increase parametrically. Then it follows that $\partial L / \partial T = \lambda_9 > 0$. In region 1, the price of pollutants must be set higher absolutely, compared to a situation ${}^oU^1 = {}^oU^2$, since $g^{1'} \lambda_9 < 0$. Raising the price of pollutants in region 1 is accompanied by a fall in the shadow price of commodities in region 1 (4.4) by a factor $H^{1'}_i g^{1'} \lambda_9 / 1 - \sum H^{1'}_i F^{1'}_{is}$, $H^{1'}_i g^{1'} \lambda_9$ accounting for the effect of pollution generation of the production activity on the fulfillment of condition (4.1). In region 2, the price of pollutants must be set lower, compared to a situation ${}^oU^1 > {}^oU^2$ and the production incentive will be stronger. The identical environmental quality restraint ensures a production advantage to region 2 and λ_9 serves to reach identical environmental qualities in the two regions.
- ii) Assume that in (2.1) we obtain ${}^oU^1 < {}^oU^2$. Then the optimal ${}^oU^2$ is reduced by restriction (4.1). Letting T decrease parametrically (i.e. letting T become negative), we obtain $\partial L / \partial T = \lambda_9 < 0$. The shadow price for pollutants in region 1 will be lower (and higher for region 2) and the level of pollution will rise in region 1 and be reduced in region 2.
- iii) If in (2.1) we obtain ${}^oU^1 = {}^oU^2$ restriction (4.1) is not binding and varying T parametrically yields $\lambda_9 = 0$. The regional effluent charges are not affected by restriction (4.1) and must be set according to the results obtained in (2.2).

V. Implications of Regionally Different Immission Norms

Insufficient information on economic and ecological processes is an important factor influencing the implementation of environmental policy. It can be realistically assumed that an environmental agency has no information on the outcome of the market process with respect to the interregional distribution of environmental quality. Then the agency can, instead of trying to achieve identical environmental qualities in the two regions, explicitly differentiate immission norms between the sub-areas of the economy. This represents a regionalized standard price approach [3, 4].

This policy of spatial separation of competing environmental uses proposed by *Mishan* [10] tries to minimize damage by concentrating pollution to some heavily industrialized areas and by protecting recreation areas. Besides an information deficit, possible justifications for this approach are that the regional welfare functions are interdependent, i.e. the recreation region is an argument in the welfare function of the industrial area, or that preserving a specific environmental area has a value per se.

Assume the policy of regionally differentiated immission norms is followed. Then we have as an additional restraint¹¹ compared to (2.1),

$$(5.1) \quad S^j \leq c^j$$

where c^j indicates the maximum permissible pollutants ambient in the environment. Introducing the slack variable $z^j \geq 0$, the additional restraint is written as

$$(5.2) \quad + \lambda_{10} [c^j - S^j - z^j]$$

Condition (2.2 iii) turns into

$$(5.3) \quad - \sum_i \lambda_i F_{is}^j - \lambda_5 g^{j'} + \lambda_{10} = \lambda_6$$

Also we have

$$(5.4) \quad \frac{\partial L}{\partial z^j} = -\lambda_{10} \leq 0$$

$$(5.5) \quad -\lambda_{10} z^j = 0$$

$$(5.6) \quad z^j \geq 0$$

The shadow price for the pollutant is given by

$$(5.7) \quad \lambda_7 = \frac{g^{1'} \frac{\partial W^1}{\partial U^1} + \sum_i F_{is}^1 \frac{\partial W^1}{\partial Q_{is}^1} - \lambda_{10}}{1 - \sum_i H_i F_{is}}$$

and for region 2

$$(5.8) \quad \lambda_7 = \frac{g^{2'} \frac{\partial W^2}{\partial U^2} + \sum_i F_{is}^2 \frac{\partial W^2}{\partial Q_{is}^2} - \lambda_{10} - \lambda_8 \alpha^{21}}{1 - \sum_i H_i^2 F_{is}^2}$$

¹¹ Observe that if perfect information were available and if regional immission restraints are motivated not by preserving an environmental good as a value per se but because of environmental quality of one area being an argument variable in the welfare function of the other region, i.e. $\partial W_1 / \partial U^2 > 0$, one can indicate how restriction (4.5) has to be set in order to maximize

$$(I) \quad W = W^1(Q^1_1, Q^1_2, U^1, U^2) + W^2(Q^2_1, Q^2_2, U^2)$$

For the effluent charge in region 2 we have

$$(II) \quad \lambda_7 = \frac{g^{2'} \frac{\partial W^2}{\partial U^2} + \sum_i F_{is}^2 \frac{\partial W^2}{\partial Q_{is}^2} - \alpha^{21} \lambda_8 + g^{2'} \frac{\partial W^1}{\partial U^2}}{1 - \sum_i H_i^2 F_{is}^2}$$

so that from (II) and (5.8)

$$\left[-\lambda_{10} = g^{2'} \frac{\partial W^1}{\partial U^2} \right]$$

in order to induce the same allocation incentive.

The shadow price for commodity i produced in region 1 is

$$(5.9) \quad \lambda_i = \frac{\partial W}{\partial Q_i} + \frac{H'_i \left[g' \frac{\partial W}{\partial U} + \sum F_{is} \frac{\partial W}{\partial Q_i} - \lambda_{10} \right]}{1 - \sum H_i F_{is}}$$

From (5.5) it follows that either $\lambda_{10} = 0$ and/or $z^j = c^j - S^j = 0$.

i) If $z^j > 0$, $\lambda_{10} = 0$ and restriction (5.1) is not binding. Since

$$(5.10) \quad \frac{\partial L}{\partial c^j} = \lambda_{10},$$

reducing the restraint constant c infinitesimally the optimal value of the objective function does not change. In this case, neither the effluent charge nor the commodity prices are influenced by λ_{10} .

ii) If $z^j = 0$, $\lambda_{10} \geq 0$ and the restriction may be binding. From (4.10) the value of the objective function is increased if c^j is set higher, i.e. if more immissions are permitted. To interpret (4.10) for this case, denote ${}^0S^j$ as the optimal value of immissions in the maximizing problem (2.1). c_j only can influence the optimal solution of (2.1) if $c^j < {}^0S^j$. Then national welfare is restrained. If, however, c^j is set so that $c^j > {}^0S^j$, no restriction is introduced. Releasing c^j increases national welfare as long as $c^j < {}^0S^j$. Consequently

$$(5.11) \quad \begin{aligned} \lambda_{10} &= 0 \text{ if } c^j \geq {}^0S^j \\ \lambda_{10} &> 0 \text{ if } S^j = c^j < {}^0S^j \end{aligned}$$

For the case $\lambda_{10} > 0$, introducing the restraint (5.1) affects the level of effluent charges and other shadow prices and consequently environmental allocation. Assume, for instance, restriction (5.1) is introduced and the restriction is binding in region 1 and not in region 2. Then λ_{17} will be higher, whereas λ_{27} will not be affected by the restriction. Consequently, polluting becomes more costly in region 1. The rise in the effluent charge is accompanied by price rises of commodities produced in region 1. Consequently, the comparative price (and the location advantage) of region 1 is changed by the restriction (5.1). From (2.2 iv) it follows that the resource price in region 1 is reduced for a given resource allocation. Consequently, the resource will move to region 2 and environmental quality will increase in region 1.

VI. Extensions

The model shows some implications for the setting of effluent charges in a two-region system. The effects of alternative policy objectives on the regional level of effluent charges and other shadow prices are discussed. Four different types of environmental policy behavior are studied: i) maximization of national welfare, ii) maximization of regional welfare

separately for each region, iii) maximization of national welfare with the restraint of identical regional environmental qualities, and iv) the restraint of different regional immission norms.

The following extensions should be considered for future research:

1. A more detailed model should explain the transformation of a given situation to a long-run optimum as a consequence of environmental policy, as discussed in section II, 3. In order to study this question, a mobility function for the resources should be introduced with the spatial reallocation of resources depending on resource prices and resource prices being influenced by effluent charges and mobility being influenced by environmental quality.

2. The transformation process from a given allocative situation to the long-run optimum also depends on the interregional exchange of commodities, so that an interregional trade and factor mobility model should be constructed as an ultimate goal.

3. It should be analyzed what will be the outcome of market processes such as migration of factors, relocation of firms and interregional commodity trade with respect to the interregional distribution of environmental quality. Also it should be analyzed what are the welfare gains from the interregional specialization with respect to environmental use for the individual regions and to what extent these welfare gains differ interregionally.

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Zusammenfassung

In einem Zwei-Regionen-Zwei-Sektoren-Modell, in dem die Wohlfahrt von der Güterproduktion und der Umweltqualität abhängt, werden die Implikationen für die optimale Faktorallokation abgeleitet. Produktionsprozesse erzeugen Schadstoffe, die die Umweltqualität negativ beeinflussen. Beseitigungstechnologien werden dabei ebenso erfaßt wie interregionale Schadstoffdiffusion. Vier Fälle werden unterschieden: i) Maximierung der nationalen Wohlfahrt durch eine nationale Behörde; ii) Maximierung der regionalen Wohlfahrt durch unabhängige Regionalbehörden; iii) nationale Wohlfahrtsmaximierung unter der politischen Nebenbedingung identischer regionaler Umweltqualitäten; iv) die Restriktionswirkungen regional unterschiedlicher Immissionsnormen.

Die Implikationen dieser vier unterschiedlichen Zielfunktionen werden abgeleitet und die der optimalen Faktorallokation entsprechenden Schattenpreise werden diskutiert.