Horst Siebert

Economics of the Environment

Seventh Edition

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Theory and Policy

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Springer

Professor Dr. Dr. h.c. Horst Siebert
President-Emeritus
Kiel Institute of World Economics
Düsternbrooker Weg 120
D-24105 Kiel
Germany

and

Heinz Nixdorf
Professor in European Integration
and Economic Policy
Johns Hopkins University
SAIS Bologna Center
Via Belmelero, 11
40126 Bologna
Italy

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Preface

The labor of nature is paid, not because she does much, but because she does little. In proportion as she becomes niggardly in her gifts, she exacts a greater price for her work. Where she is munificently beneficent, she always works gratis.

David Ricardo[1]

This book interprets nature and the environment as a scarce resource. Whereas in the past people lived in a paradise of environmental superabundance, at present environmental goods and services are no longer in ample supply. The environment fulfills many functions for the economy: it serves as a public-consumption good, as a provider of natural resources, and as receptacle of waste. These different functions compete with each other. Releasing more pollutants into the environment reduces environmental quality, and a better environmental quality implies that the environment's use as a receptacle of waste has to be restrained. Consequently, environmental disruption and environmental use are by nature allocation problems. This is the basic message of this book.

If a resource is scarce and if a zero price is charged for its use, then misallocation will result. The environment as a receptacle of waste has been heavily overused, and consequently environmental quality declined. Scarcity requires a price. This book analyzes how this price should be set, whether a correct price can be established through the market mechanism, and what role the government should play. The book offers a theoretical study of the allocation problem and describes different policy approaches to the environmental problem. The entire spectrum of the allocation issue is studied: the use of the environment in a static context, international and trade aspects of environmental allocation, regional dimensions, environmental use over time and under uncertainty. The book incorporates a variety of economic approaches, including neoclassical analysis, the public-goods approach, benefit-cost analysis, property-rights ideas, economic policy and public-finance reasoning, international trade theory, regional science, optimization theory, and risk analysis.

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[1] D. Ricardo, *Principles of Political Economy and Taxation*, 1817, quoted according to Everyman's Library, London 1911, Dent, p. 39.

This book grew out of my research at the University of Mannheim, of Konstanz and at the Kiel Institute for the World Economy, Germany, and visiting positions at the University of Aberdeen, Scotland, the Australian National University in Canberra, the Energy Laboratory of the Massachusetts Institute of Technology as well as the Sloan School of Management, the University of California at Riverside, the University of New Mexico at Albuquerque, New York University, and Resources for the Future in Washington. I appreciate critical comments to previous editions from Ralph d'Arge, Ferdi Dudenhöffer, Helga Gebauer, Ralf Gronych, Gernot Klepper, Allen V. Kneese, John V. Krutilla, Ngo Van Long, Peter Michaelis, Toby Page, David Pearce, Rüdiger Pethig, Michael Rauscher, Cliff Russell, Hans Werner Sinn, Walter Spofford, Frank Stähler, Sabine Toussaint, Wolfgang Vogt, and Ingo Walter. For this edition, I received critical comments from Rüdiger Pethig and Michael Rauscher. My research assistants Mark Bousfield, Alexander Schrats, and Michael Trinkus helped to update data. Michael Trinkus has prepared the bibliography.

I am delighted that this book has been accepted by the international academic community as a standard work in the economics of the environment, including editions in Chinese (2001) and in Japanese (2006). This seventh edition has been systematically revised and enlarged. Empirical references, tables, and figures have been updated. The recent literature has been integrated into the text. New sections have been added on abatement costs, ambient air quality standards in the European Union, environmental legislation, the empirical relationship between trade and environmental quality, global warming, self-enforcing contracts, the Kyoto Protocol and other global approaches, and EU emission trading.

I hope that the analysis presented in this book contributes some insights to the emotional debate on environmental disruption, and I wish that it incorporates nature and the environment as a scarce good into the body of economic thought and that it provides an answer of economics as a discipline to a problem of great importance to our societies.

Horst Siebert

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Part I
Introduction

1 The Problem

Air and water have long been prototypes of free goods, available in unlimited quantities with no price attached to their use. The Rhine River, with its fairy tales and romantic songs, is an example. It has been used as a common property resource in a manner similar to the ozone layer and the oceans. Natural resources have been employed in economic activities without consideration of the long-run effects on the life-supporting systems of the planet or the potential losses to future generations. The joint outputs of consumption and production activities have not been factored into the calculation of the economic system. In short, the environment, as the set of natural conditions defining the human living space, has not been taken into consideration by economic theory.

Since the late 1960s and the early 1970s, we have become increasingly aware of environmental disruption. The environment has fallen from the paradise of free goods to the realm of scarcity:

> Since the 1970s, the Los Angeles Times publishes a daily smog report in which the local level of pollution concentrations is noted, such as carbon monoxide and nitrogen oxide. Other newspapers have followed.
>
> There was no oxygen in the atmosphere when the earth came into existence; rather, it took 3 billion years for oxygen to appear through the photosynthesis of slowly evolving plants. Today, the photosynthesis of phytoplankton in the oceans supplies about 70 percent of the oxygen demand of the earth. Scientists are concerned with pollution of the oceans.[1]
>
> Since the 1990s, natural scientists have been worried about the depletion of the ozone layer, the increased carbon dioxide concentration in the atmosphere, and global warming.[2]
>
> Numerous experiments and epidemiological data suggest that there is a relationship between air and water pollution and a variety of illnesses.[3]

From the economist's point of view, the environment has become a scarce commodity. Scarcity means that competing uses exist for a given good and that

[1] National Oceanic and Atmospheric Administration (NOAA) of the United States (2002).
[2] See Stern 2007, Unep 2007.
[3] On data compare Holgate (1999).

not all demands for its use can be satisfied. The environment is used as a public-consumption good, as a provider of natural resources, and as a receptacle of waste. Since the demand for different uses is greater than the supply, some of the competing uses have to be reduced or eliminated. The challenge is to determine which potential uses deserve priority.

Environmental use poses an allocation problem. That is the message of this book. In chapter 2, we study the basic structure of this allocation problem. In the past, the environment was used as a common-property resource at a zero price. This was especially true of its role as a receptacle of waste. This institutional setting of a zero price implies an overuse of the environment and a decline in environmental quality. It also causes private and social costs of production and consumption to diverge. Commodity prices do not indicate the true opportunity costs of economic activities, and so pollution-intensive activities become too large relative to an allocation optimum. Sector structure is distorted in favor of the pollution-intensive sector, and too many resources of production are attracted to the pollution-intensive sector. The solution to the environmental problem lies in reducing the divergence of private and social costs and introducing an institutional framework for market economies such that all costs of economic activities are attributed to the individual unit.

After introducing the economic dimension of the environmental problem in part I, we analyze its static allocation aspect in part II. Policy implementation is discussed in part III. The spatial aspect of the environmental problem including the international dimension is examined in part IV. Finally, in part V, we consider the intertemporal allocation problems including uncertainty.

Throughout the book, the same basic model is used. The underlying assumptions with respect to the production side are presented in chapter 3. Emissions are interpreted as joint products of output. Also it is assumed that factors of production are used for abatement. For simplicity, a two-sector model of the economy is considered. The transformation space, that is, the production possibilities with respect to private goods and the public-good environmental quality, is analyzed. It is shown that there is a tradeoff between the production of private goods and environmental quality. A higher environmental quality results in fewer private goods, and concomitantly, more private goods can be obtained only at the cost of a lower environmental quality.

In chapter 4, optimal environmental allocation is defined so that a frame of reference for environmental policy is established. The implications of the optimum are studied. We can indicate how the price mechanism has to be corrected in order to take into account environmental quality. We can specify how a shadow price for pollutants, that is, an emission tax, has to be set. Also we can show that if a correct emission tax is chosen, the optimum can be reached with a competitive equilibrium.

Chapter 5 focuses on the public-goods approach to the environmental problem. If environmental quality is a public good, property rights cannot be defined and government intervention becomes necessary. The problem arises as to how the government determines environmental quality. The social-welfare function, benefit-cost analysis, and the aggregation of individual preferences are studied as alternative approaches. According to the Lindahl solution, a Pareto-optimal allocation of the environment requires individualized prices of environmental quality to be differentiated according to the individual's willingness to pay. The individual, however, can take the position of the free rider and not reveal his or her true preference. Therefore we have to investigate institutional arrangements which will reveal and aggregate individual preferences.

The property-rights approach described in chapter 6 represents the counterpoint to the public-goods discussion. If property rights can be adequately defined, optimal allocation will be attained through private decisions, and government intervention will be necessary only in order to define and secure property rights. In fact, it is conceivable that property rights could even be established through private bargaining without any government intervention. The Coase theorem (1960) shows that under specific conditions the allocation result is independent of the attribution of property rights. The salient point is that property rights must be assigned. It may not be feasible to make the free-rider problem disappear in determining optimal environmental quality by defining property rights, but in any case new property rights have to be set up for the use of the environment as a receptacle of waste.

In part II, the static allocation aspect is discussed from a theoretical point of view. In part III, policy aspects are studied. From a pragmatic standpoint, we may start from the assumption that environmental policy has set an environmental-quality target. The problem, then, is to determine how this target can be transformed to the emission behavior of the polluters. In chapter 7, we use the theoretical framework of our model to consider how producers react to an emission tax. First, we use partial equilibrium analysis for a given commodity price and for perfect competition. We also look into the question of whether a monopolist can shift the emission tax. Finally, we use a general equilibrium framework in which the emission tax also affects relative price and in which the demand side of the economy is taken into consideration. In chapter 8, we contrast regulation through permits, emission taxes, pollution licenses, the bubble concept, cost sharing, and liability as mechanisms for translating quality targets into individual behavior. The advantages and the disadvantages of different policy instruments are reviewed. In chapter 9, we develop the idea that the merit of a specific policy instrument depends on the casuistics of the environmental problem. Solid waste, emissions from mobile sources, environmental accidents, vintage damages, pollutants in consumption goods, and externalities in land use are considered.

In chapter 10, we study some issues of the political economy of environmental scarcity. The basic principles of a rational environmental policy are developed such as recognizing the opportunity costs, attributing them to the decentralized units, having a long-run orientation in preventing future damages, securing continuity in the policy approach, and not neglecting the interdependence among pollutants and among environmental media. We then discuss why these rational principles are not adhered to in environmental policy in the real world.

In part IV, we introduce the spatial dimension of the environmental system to our analysis. In reality, environmental systems are defined over space. We may distinguish among global systems, such as the ozone layer; international environmental goods, such as the quality of the Mediterranean Sea; transfrontier pollution systems, such as the international diffusion of acid rains; national environmental media and regional assets as subsystems of nations, such as the air region of a metropolitan area. In chapter 11, the interrelation between environmental endowment, competitiveness, and trade is highlighted. We look into the problem of how environmental abundance or scarcity affects comparative advantage, the terms of trade, and trade flows. Since environmental policy must be embedded in an international context, the trade repercussions of environmental policy are of utmost importance.

The issue of transfrontier pollution is studied in chapter 12. We look at institutional solutions for transnational spillovers and incentives to cope with free-rider behavior. How do a noncooperative and a cooperative solution differ? Can side payments help in bringing about a cooperative solution? Global environmental media are studied in chapter 13. In the past, they have been used as open access resources with no scarcity prices being charged for their use. The noncooperative and the cooperative solutions are analyzed. The role of side payments is discussed. Elements of a workable permit system are developed.

In chapter 14, regional environmental allocation is analyzed. Should all areas of a country strive for an identical environmental quality, or should the quality targets be differentiated among regions? Should policy instruments be uniform for a nation, or should they be different for different areas? What are the implications of an environmental policy that is established by autonomous regional authorities compared to a nationally formulated environmental policy?

In part V, the time and risk dimension of environmental allocation is examined. The environment will be used not only by the present generation but also by future generations. Pollutants such as DDT may accumulate over time so that future generations will inherit our stock of pollutants. Or, on the positive side, succeeding generations will enjoy the benefits of abatement capital and abatement technology which we have invented. In chapter 15, we determine the optimal intertemporal allocation of environmental use and its implications. The problem is to decide which stock of pollutants can be safely passed on to future generations if we take their well-being into consideration. In this context, the optimal time path of an emission tax is studied. In chapter 16, we deal with the problem of economic growth; here we are interested in the extent to which environmental quality targets may represent a brake on economic growth. Also the interrelationship between growth and natural resources is investigated. Finally, in chapter 17, we study the use of the environment in its different functions when damages in the future are uncertain. The implications of such a risk on the optimal environmental quality to be reached and on the policy instruments are discussed. Moreover, other problems relating to risk management such as irreversibilities and approaches to allocate the costs of risk reduction to the decentralized units of an economy are described.

2 Using the Environment – An Allocation Problem

Externalities

Technological externalities are nonmarket interdependencies among economic activities. Consider, for example, two production activities i and j. An externality exists if the output Qi in activity i depends on the output Qj or on the inputs Rj of the other activity. Thus

$$Q_i = F_i(R_i; Q_j, R_j) \tag{2.1}$$

where

$$\frac{\partial Q_i}{\partial Q_j} \neq 0 \quad \text{or} \quad \frac{\partial Q_i}{\partial R_j} \neq 0$$

If the output of good i increases while the output of good j is rising, then positive externalities exist. If the output of good i decreases while the output of good j is rising, then negative externalities will prevail (for example, open-pit mining may reduce the water-table level and consequently affect the productivity of surrounding agricultural fields). In addition to interdependencies among production activities, there are technological interactions among consumption activities (the thesis of "conspicuous consumption" by Veblen[1]) and between production and consumption activities (cement plant and housing areas, for example).

In the past, economists have taken an interest in externalities (for example, Pigou 1920) because externalities violate a condition for the optimality of a competitive equilibrium in a market economy. In this case, the question arises as to whether the set of autonomous decisions by individual units constitutes an optimal allocation. While analyzing externalities, however, the economists have not taken into account the "technological" systems through which the economics activities are linked to one another (for example, the groundwater system in the open-pit-mining example). One such system linking economic activities is the environment. The examination of these intervening systems permits new insights into the problem of externalities.

---

[1] Th. Veblen, *The Theory of the Leisure Class* (London: Allen and Unwin, 1925).

Although the Pigouvian analysis of technological externalities indicated the right direction for correcting the externalities by a "Pigouvian tax" on the activity causing the negative externality, it was deficient in two important aspects: First, it did not analyze the "technological system" by which economic activities are linked (besides the interdependence via markets). By explicitly introducing the technological system of an externality, in our case the environment, a richer structure can be given to the environmental issue.[2] Second, an explicit analysis of the technological system provides the clue for defining incentives to avoid externalities – not in the general form of a "Pigouvian tax", but by setting a price on emissions.

Relationship Between the Environment and the Economic System

The environment may be understood to be the set of natural conditions that defines the human living space. It has become customary to distinguish among different environmental systems such as air, water, and land. Within these categories, one may consider such subdivisions as the meteorological region of a metropolitan area, atmospheric conditions in a region of the world such as the Northern Hemisphere, or global systems such as the earth's atmosphere or the ozone layer. In the following analysis, the term *environment* may be understood to be a specific environmental system.

In an economic interpretation, the environment has four functions. Figure 2-1 illustrates these functions.

Consumption Good

The environment provides public goods for consumption such as air to breathe, the amenity of the landscape, and the recreational function of nature (arrow 5 in Fig. 2-1). A public good is characterized by two features: First, a public good, contrary to a private good, can be used by several individuals at the same time without the users competing with one another. There is no rivalry in use. This possibility of collective use or nonrivalry is not a sufficient characteristic of a public good because collective consumption also exists for many private goods, at least up to a certain point (for example, a bullfight). Second, a public good does not permit the exclusion of competing users. An outstanding example is the lighthouse which can be used as a checkpoint at sea by every fisherman regardless of whether he wishes to share the costs. In addition to this technical impossibility of exclusion, there are several goods for which an exclusion technically is possible (fees for attending school or fees

[2] The analysis of externalities clearly benefits from the explicit introduction of the technological system by which economic activities are interrelated. More specifically, technological externalities imply a technological system; an interdependence via markets including future markets does not constitute a technological, but a "pecuniary externality".

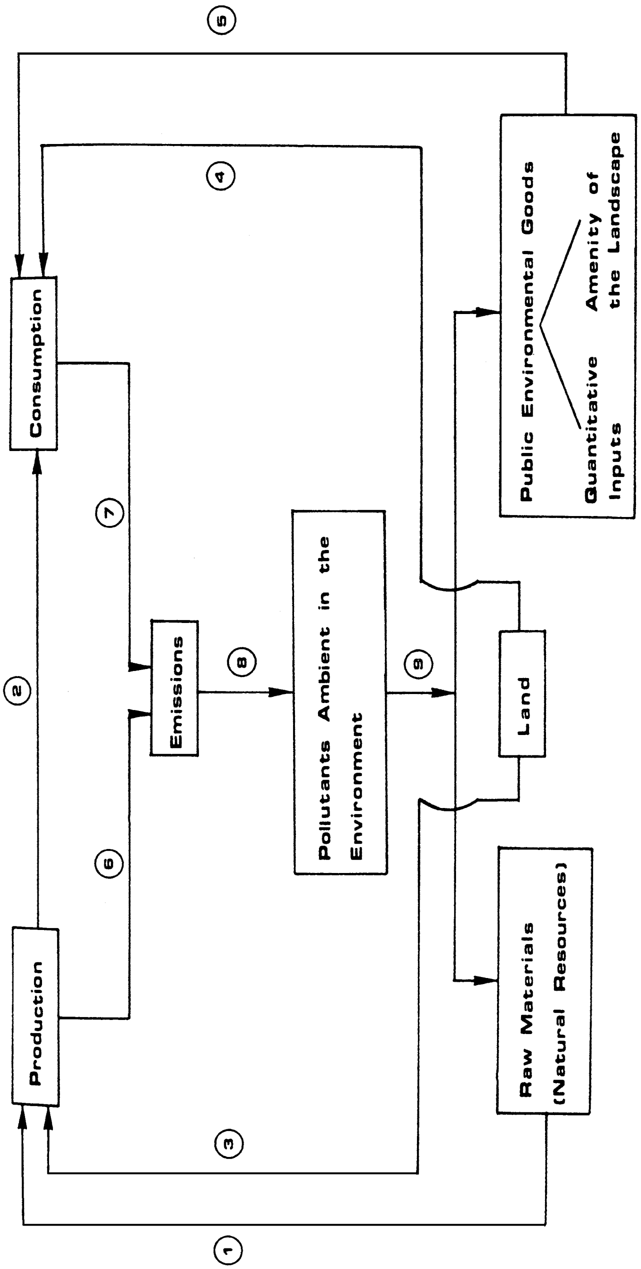

Fig. 2-1. Interaction between the environment and the economy

at a university), however, one dispenses with the exclusion of potential users owing to normative considerations. Therefore, some define a *public good* as a commodity from whose use no one can or should be excluded. The nonexclusive character of the public good can be very often traced to a value judgment or a supposedly nonexisting exclusion technology (compare chapter 5).

Environmental quality as a consumption good is such a public good. A technical exclusion, as far as it is possible, is not desirable, and the good can be used by all individuals. The environment as a public good for consumption can be used in two ways: First, the environment provides consumption goods that are measurable in physical units, such as oxygen in pounds inhaled per minute. Second, the environment provides consumption inputs which are only qualitatively valued (say, the amenity of the landscape). While in the first case mass flows from the environment to consumption, this does not necessarily apply in the second case.

In order to simplify the following analysis, we consider environmental quality to be a public good without delineating different kinds of consumptive inputs.[3] A more detailed analysis of the public-good "environment" should define acts of consumption such as swimming, breathing, and so on. Then one would view these acts as the result of inputs to consumption, to which the environment contributes in a quantitative as well as a qualitative way.

Supplier of Resources

The environment provides resources that are used as inputs in production activities, for example, water, sun, minerals, oxygen for combustion processes, and so on (arrow 1 in Fig. 2-1). The commodities generated by the resources are supplied for consumption (arrow 2). In Fig. 2-1 the economic system is characterized by production, consumption, and emissions; the environmental system is distinguished by raw materials, land, public environmental goods, and pollutants ambient in the environment.

Receptacle of Waste

The joint products (arrows 6 and 7) of the production and consumption activities which have no further utility are emitted into the environment. Joint products exist when several goods are produced at the same time. Often the joint product cannot be used; for example, carbon oxide and sulfur dioxide arising from burning fossil fuels and carbon monoxide as well as nitrogen oxides produced by our cars are undersirable by-products. For instance, in

[3] In the following text, we use the term environmental quality for simplifying purposes, although the public good environment definitively has a quantitative characteristic, for instance pounds of oxygen consumed.

Germany, 0.6 million tons of sulfur dioxide were produced in 2000, mostly from electricity generation, 0.9 million tons of nitrogen oxides, mostly from transportation, and 0.9 million tons of carbon dioxide.

The reception of emissions, that is, of joint products no longer utilizable, is the third function which the environment fulfills for the economic system (arrows 6 and 7). The environment is used as a sink.

The emitted pollutants are absorbed by different environmental media: atmosphere, land, and water. Then the pollutants are partly decomposed, accumulated, transported to other areas, or transformed. Emissions, therefore, are not identical with pollutants ambient in the environment. Emissions are the undesired joint outputs of production and consumption activities. Pollutants are ambient in a certain environmental medium at a certain time. Emissions are changed into pollutants by diffusion or transformation processes in the environment (arrow 8). The distinction between emissions and pollutants ambient in the environment is important. One must always refer to pollutants when defining the target variable "environmental quality". However, economic policy must be directed against the emissions.

In this context, the innovation of environmental economics over the traditional Pigouvian analysis becomes apparent. Pigou could only indicate the direction of correcting the externality, but the Pigouvian analysis did not point out emissions as the basis for a price on negative externalities.

The pollutants ambient in the environment at any certain time influence the quality of the environmental services, namely, the public-consumption goods and raw materials. This relationship results from the fact that pollutants can affect the characteristics of environmental systems. Thus, pollutants influence air quality; or they may negatively affect a beautiful landscape by reducing visibility, as is the case in the four corner areas of the southwest United States. The behavior of ecosystems or meteorological systems may be changed. For instance, air pollution may reduce the growth rate of trees or may even lead to their destruction. We define this relationship by a damage function (arrow 9).

Note that at first glance this function may be interpreted as an index function since, in our simple approach, pollutants both influence and define environmental quality (for instance, in parts per million). However, environmental quality may also be measured in terms of characteristics other than pollutants, such as the height of trees, longevity of plants, abundance of wildlife, and so on. Then the damage function can no longer be understood as an index function. The damage function is understood here in a technical sense; damages are measured in physical units or in qualitative terms, but they are not yet evaluated in money terms.

In the literature, the damage function has been interpreted in a broader sense. Pollutants may not only have an impact on environmental quality as a public-consumption good or raw materials (that is, nature), but also influence production processes (for instance, air pollution may lead to a quicker corrosion of railway tracks or building facades or result in a lower production output).

Location Space

Finally, the environment which is defined over space provides space for location for the economic system, namely, land for industrial and residential locations, agricultural land, and land for infrastructure. This function is similar to the provision for raw materials.

Lately, the different functions of the environment are summarized by the term "ecosystem services" (Daily et al. 1997).

Material Flows Between the Environment and the Economic System

To the extent that the interdependence between the environment and the economic system is not of a qualitative nature, the interrelationship can be described in an input-output table (Leontief 1970). Figure 2-2 illustrates such a simplified table. While regarding the economy as a set of sectors which produces for final demand (consumption, capital investment, export, and governmental demand), square 1 in Fig. 2-2 denotes the interdependence between the sectors and final demand. An additional split of square 1 would include, for example, those quantities which sector *i* provides for sector *j* (intermediate demand) or for final demand. The output of a sector would be listed in the rows, and its inputs in the columns.

Square 2 contains the outputs of the environmental system which are used as inputs in the different economic sectors (raw materials, water, and oxygen) or which go directly to final demand (oxygen) without having been used in a production process. Square 3 comprises the output of the economic system into the environment, namely, the emissions occurring in the production and consumption activities. If one imagines the economy has been sectorally disaggregated, squares 2 and 3 indicate the environmental inputs by sectors and the sectoral sources of emissions. A disaggregation of the environment, that is, in ground, water, and air systems, shows from which environmental system natural resources come and to which sectors of the environment emissions go. Finally, square 4 indicates flows among the branches of the environment.

The interdependencies of quantitative supply between the environment and the economy (listed in Fig. 2-2) are of such a nature that the mass withdrawn from the environment must flow back to it. Because of the mass-balance con-

Inputs / Outputs	Economy	Environment
Economy	1	3
Environment	2	4

Fig. 2-2. Input-output system of the economy and the environment

cept, mass cannot be lost (Kneese, Ayres, and d'Arge 1970). Looking at specific products, the mass-balance concept has given rise to the concept of closed substance cycle. Note, however, that mass must not flow back to the environment during the period in which it was withdrawn. With capital formation, durable consumer goods, and recycling, it is possible that masses taken from the environment today are emitted into the environment in later periods.[4]

Appendix 2A represents the input-output approach for calculation the quantity of pollutants (in tons) which are generated per $ 1 million of final demand for a product (pollutant loading of a product). Moreover, other applications are indicated.

Competing Uses

The four functions of the environment (public good for consumption, supplier of raw materials, reception medium for pollutants, and space locations) described are competing with one another if the demand for the environmental service cannot be met at a given environmental endowment. The fact that the environment can be utilized for different purposes is one of the chief reasons br the environmental problem. In the following analysis, these competing uses are examined more closely.

Congestion of Public Goods

I consider a single use of an environmental medium and ask to what extent its quality is negatively affected by the number of users. Pure public goods can be used by all individuals to the same extent owing to the nonexistence of an exclusion technology. Let U_l^A denote the quality U of the public good l used by individual A. Then we have for the pure public good

$$U_l^A = U_l^B = \ldots = U_l^Z = U_l \tag{2.2}$$

The congestion problem, on the other hand, is characterized by the fact that environmental goods have a capacity limit. As soon as the intensity of use surpasses capacity, the quality of the public good is negatively affected. Let N denote the quantity of users and $\bar{N}$ the capacity limit. An additional user $N > \bar{N}$ affects the quality of the public good negatively (for example, the quality of a national park inundated by a great number of visitors). Thus

$$\frac{dU_l^A}{dN} = \frac{dU_l^B}{dN} = \ldots = \frac{dU_l^Z}{dN} = \frac{dU_l}{dN} \begin{cases} <0 & \text{for} \quad N > \bar{N} \\ =0 & \text{for} \quad N \leqslant \bar{N} \end{cases} \tag{2.3}$$

[4] The implications of the transformation of mass into energy in the mass-balance concept are not discussed here. Also compare the problem of entropy.

For congestion, the definition that a public good can or should be used by everybody simultaneously still applies. However, the public good that is to be used has changed in its quality. The problem, therefore, is determined by a qualitative scarcity restriction. Beyond the capacity limit, an additional user unfavorably affects the quality of the public good available for other users.

The problem of congestion of public goods can be related to spatially limited environmental goods (say, national parks) or to the entire human living space. In this global interpretation, the environmental question can be understood as a congestion problem as described by Boulding's (1971 b) paradigm of the spaceship earth: the growth of the world's population affects the quality of the human living space when the economic system has negative impacts on the environment, when space is limited, when the given raw materials are depletable, and when the regeneration functions of renewable raw materials are limited. Two components are constitutive in order for this global congestion problem to arise: First, the demand for the globally interpreted good "environment" must increase as a result of population growth, economic development (if the income elasticity of the demand for environment is greater than 1), or a change of preferences in favor of the public good "environment" as a result of development processes. Second, the supply of the good "environment" must be limited.

In the following analysis, the environmental question as a global congestion problem is explained by a more detailed consideration of some (quantitative and partly qualitative) constraints, that is, competing uses. These competing uses have to be considered against the background of a rising demand for environmental goods. Moreover, the congestion of environmental goods has to be considered as one reason for the global congestion problem.

Conservation

There is a competitive use between the role of the environment as a public-consumption good (for example, aesthetic values of nature and landscape, biodiversity) and its function as a location for economic activities. Krutilla (1972), influenced by the conservation movement, illustrates this problem with the Hells Canyon case where a natural amenity may be given away for the mining of raw materials. Another example of competing uses in time is turning the cathedral of Notre Dame in Paris into a parking lot (Henry 1974). Also, it cannot be excluded that competing uses occur within the basic function "public-consumption good" itself (for example, a lake used as a drinking-water reservoir or for motorboats).

Let U_l denote the quality of environmental good l, for example, of a national park. Note that the quality of a public good also implies a minimal spatial extension. Let M_k denote the amount of land for location of the type k, let R_h describe the quantity of a resource R, and let U_L represent another environmental good L. Then the competitive use can be written as

$$U_l \geqslant \bar{U}_l \Rightarrow \begin{array}{l} M_k = 0 \\ R_h = 0 \\ U_L = 0 \end{array} \tag{2.4}$$

That is, the supply of a certain quality $U_l \geq \bar{U}_l$ excludes the simultaneous use of land for location, as mining ground, and the supply of another public good L. This competing use is binary in the sense of an "alternative" and exclusive character. Equation 2.4 can also be formulated as a quantitative restriction of land use expressed in square meters. One specific aspect of these competing uses is mainly that a minimum quantity of the public good must be used since the public good is not divisible.

Another qualitative aspect of this restriction is that allocation decisions can be unilaterally or reciprocally irreversible. The mining of raw materials in Hell's Canyon today will preclude its later use as a national park; in contrast, however, its use as a national park will not prevent (technically) the mining of raw materials at some future date. This (intertemporal) irreversibility has to be considered when decisions are made about resource allocations.

Raw-Material Problem

The demand to preserve natural systems for the future can compete with the raw-material supply function of the environment for the present generation. This happens, for instance, when the raw materials withdrawn from the environment are not renewable. Then the question arises as to which alternative uses the scarce raw materials should be allocated. In this regard, the static conflict is not as interesting as the competing alternative uses of raw materials over time. In the case of raw materials, an additive restriction of the form

$$\sum_i R_{hi} \leqslant R_h \tag{2.5}$$

can be given. The withdrawals of nonrenewable materials have to be summed over time, with R_h denoting the total usable resource for all periods. For renewable resources, R_h has to be explained by a regeneration function.

Use of Space

The factor land can be considered to be a special case of resources that cannot be regenerated. A number of different economic allocations compete for the factor land, for example, land for the location of agriculture, industry, residential areas, mining, and infrastructure. If j denotes the different allocation possibilities of land of type k, the additive (that is, quantitative) restriction is

$$\sum_k \sum_j M_{kj} \leqslant M \tag{2.6}$$

Within this additive restriction, irreversibilities also arise because the structure of an area can be interpreted as an embodiment of past locational decisions or as ossified decisions of the past. The given spatial structure influences the topical choice of location. Therefore, restriction 2.6 should also be interpreted with reference to time.

Pollution

This case of competing uses is characterized by the fact that the environment can be used as not only a public-consumption good, but also a receptive medium for pollutants. The damage function in Fig. 2-1 expresses this competing use.

The concepts of competing uses and negative externalities reflect the same empirical phenomenon but from a different point of view. The concept of competing uses begins with environmental goods and examines alternative purposes for which an environmental good may be used. The concept of negative externalities, however, starts out from an economic activity and encompasses the effects of externalities on other activities. In both approaches the environmental system represents a technological link between two economic activities. We can summarize: Competing uses are one reason for externalities; negative externalities in the environment are the consequences of unsolved competing uses. Both formulations are attempts to explain the same problem, namely, the problem of environmental disruption.

Zero Price of Environmental Use

The environmental problem is one of competing uses and is, therefore, a question of scarcity. Thus using the environment presents itself as an allocation problem to the economist. The question is how the environment should be allocated to the various competing uses.

In the following discussion, the congestion problem, the conservation issue, and the question of land use are not examined. We concentrate on the question of environmental pollution.

In the past, the environment was often used as a receptive medium for pollutants at a negligible price. The institutional arrangement for the use of nature's sources did not put a price on the environment. The environment was used like the commons in the Middle Ages; it was regarded as a common-property resource. The term *common-property resource* is referred to here as an institutional arrangement which defines the use of natural resources in a specific historical setting. These goods were treated as free goods with no price being attached to them.

Common-property resources may or may not be identical to public goods. The pure public good is defined by nonrivalry of use (and by nonexisting exclusion technologies). Common-property resources are defined with respect to a prevailing institutional framework of pricing environmental services. If natural goods are treated as common-property resources because no exclusion technologies exist, they are also public goods (compare chapters 5 and 6).

What is the consequence of a zero price for a natural resource? Such an institutional arrangement of environmental use produces a discrepancy between private and social costs and a suboptimal allocation of the environment as well as of the production factors, labor and capital. Costs are the evaluated inputs of factors of production. *Opportunity costs* are defined as the utility loss of a forgone opportunity. The opportunity costs of resources used in the production of good A consist of forgone opportunities of producing good B (next best opportunity). With a zero price for environmental use, the opportunity costs, then, are not fully appreciated. Suppose that water is used as a receptive medium for pollutants by the pulp and paper industry. Then the opportunity costs may be given, for example, by those utilities forgone in the use of the water for the production of beer or, if the water can be processed, by those costs associated with the processing. Alternatively, if the water is to be used for drinking purposes, the alternative costs lie in the forgone consumption of drinking water. The opportunity costs of a phosphate open-pit mine are the decreases in productivity of the agricultural fields nearby. To cite another example, the alternative costs of air as a receptive medium for pollutants consist of health damage resulting from pollutants.

If the opportunity costs of environmental use are not considered in private decisions, there will be a discrepancy between social and private costs relating to an individual business. Private costs denote factor inputs evaluated from a single activity's point of view. Social costs comprise all costs of an economic activity. Therefore, social costs include not only the value of production factors used by an individual business, but also negative externalities in other units of the economy. In the case of environmental disruption, social costs also include the impairment of environmental quality.

A zero price does not solve the problem of competing uses. Its effect is that private costs and social costs diverge from each other. The accounts of single economic units consider only private costs, not those costs caused by negative externalities in other economic units.

The discrepancy between private and social costs is significant because the prices of goods do not always include all social costs that come about during production. This means that the prices of goods which are produced with a high pollution intensity do not reflect their environmental nuisance. Further, it signifies that the costs of these goods are calculated at a price that is too low. What are the consequences of this cost omission? Consider two products, one being produced with a high proportion of pollution and the other being produced with less pollution. If no price is demanded for the damage done to the environment, the price of the detrimental product does not include the social opportunity costs of the environmental damage. The price of the product that damages the environment is too low. Therefore, the demand and the production of the pollution-intensive good are too high. We have, then, two different allocation effects:

First, the use of the environment at a zero price leads to an overproduction of ecologically harmful products. This means that too many resources are employed in the pollution-intensive sector and too few in the environmentally favorable sector. The distortion of the relative prices thus causes a systematic distortion of production in favor of the ecologically damaging products. A zero price for environmental use, then, can be understood to be an artificial production benefit for the pollution-intensive sector.

Second, the common-property resource is overused since no price is charged for it. The consequence is environmental degradation.

With a zero price for environmental use, the economic system does not include automatic control mechanisms that check an overuse of the environment and a distortion of the sectoral structure. The economic system does not provide incentives to reduce pollution. On the contrary, it systematically favors the products which damage the environment. From the previous analysis it follows that a zero price cannot bring about an optimal allocation of the environment among competing uses. A solution to the environmental problem can be achieved only be deciding which of the competing demands on the environment is of primary importance. Scarcity calls for the introduction of prices. In the following analysis, we examine the institutional arrangements through which prices can be determined so that polluters are forced to take into account the negative externalities caused by them. Thus, our question is: How can we best implement the polluter-pays principle?

Environmental Effects of Government Decisions

In addition to the effects of economic decisions in the private sector, government activities also influence the quality of the environment. A large part of today's energy supply is provided by government-influenced enterprises. Since the generation of energy is one of the critical factors responsible for the development of pollutants ambient in the air, the government can play an important part in determining environmental quality. Furthermore, government instruments that have direct and indirect impacts on space, for example, in regional planning, influence environmental quality. Other measures, such as stabilization policies, which at first glance hardly seem to affect the environment can also have an impact on environmental quality. In the past, environmental effects were not taken into consideration in government decisions. The government, as well as the private sector, had not included the environment in its calculations and so had put the environment at a zero price for its purposes. Consequently, one of the reasons for environmental degradation has been due to government activity.

How Much Environmental Quality?

If a scarcity price has to be determined for the environment, how should this price be set? Can the market establish such a price? As a first answer, economists tend to conclude not since the environment is a public good, that is, it seems property rights for the environment cannot be clearly defined. A more detailed analysis, however, suggests that property rights to use the environment as a receptable of waste can be established. The assignment of such property rights may be accomplished by private bargaining or by the government restructuring the institutional framework of the market economy. One way of doing this is through the introduction of transferable emission licences or of emission taxes, that is, effluent charges. In this context, we have to consider the question of which environmental quality we should set. The strength of transferable emission licences or of an emission tax clearly depends on the level of environmental quality being sought. Since reaching a specific environmental quality level will imply costs, the benefits and costs of environmental policy should be considered. Also, the political processes through which the target variable "environmental quality" is determined is of interest in our analysis.

A Taxonomy of the Environmental Problem

Theoretical models always abstract from real aspects of a problem. Therefore, it is worthwhile to survey the main components of a problem even if some aspects are not analyzed later. The environmental problem, then, should take into account the following aspects.

Environmental Media. Air, water, land, and natural ecological systems are the environmental media mentioned most often. Depending on the medium to be considered, specific problems are to be dealt with. For instance, the diffusion function differs among environmental media. It may be easier to find solutions to the environmental problems of smaller systems, such as a pond in a local neighborhood, than for larger systems, such as the ozone layer of the world. Purification may be possible after emissions have entered one medium (water) but not another (air).

Spatial Extent of Environmental Media. Environmental media may be local, regional, national, international, or global.

Form of Appearance of Pollutants. Pollutants may arise as joint outputs of consumption or production. This is the case with which I concern myself mostly in this book. Pollutants may also be found in consumption goods such as DDT in agricultural products (the case of the apple). Then they are not joint outputs, but rather joint inputs, for instance, in consumption processes.

Pollutants may be linked to using a specific good, either a consumption good or an input (the case of the diesel). Pollutants may also be found in new products that enter the market, such as chemicals.

Pollutants may arise in a regular fashion (smoke stack) or at random in environmental accidents (Bhopal, Seveso, Sandoz). Finally, pollutants may arise when consumption or capital goods are discarded into the environment (beer cans, cars, refrigerators).

Type of Pollutants. Pollutants may differ with respect to their properties (organic wastes, chemical properties). They may be poisonous, damaging in the long run, or neutral.

Origin of Pollutants. Pollutants may stem from raw materials or from energy. They may come from stationary or mobile sources.

Time Pattern of Generation. Pollutants may occur in a continuous or random fashion (Bhopal, Seveso, Sandoz). Examples are emissions from smoke stacks and technical accidents, respectively.

Longevity of Pollutants. Pollutants may be easily absorbed by environmental media, such as organic wastes in water, or they may take longer, as is the case with DDT with respect to the food chains in nature. Consequently, we may distinguish between short-, intermediate-, and long-term problems.

Appendix 2A: Input-Output Analysis and the Environment

Input-output analysis can be used to analyze relationships between the economic system and the environment (Leontief 1970). Assume a linear function between the quantity of waste product h and the output level of sector K to be

$$W_h = d_{hK}X_K$$

where X_K can be defined in physical as well as in value terms. The vector of the wastes w is given by $w = Dx$, where D denotes the matrix of the coefficients d_{hK}. For a given final demand y, in reference to the function $x = (I–A)^{-1} y$, the vector of the pollutants is given by $w = D(I–A)^{-1}$ y.

In this manner, the vector w of the waste products is determined by a secondary calculation (Leontief and Ford 1972). It is also possible to determine the vector of the waste products endogenously by introducing w into the model. In this case, the matrix A is extended by the matrix D. The resulting matrix $\begin{bmatrix} A \\ D \end{bmatrix}$ is not quadratic and so it is not applicable to input-output analysis. Nevertheless, it is applicable to problems of linear programming.

However, if the assumption is made that the activities w can abate waste products, then a quadratic matrix is given. The problem is

$$\begin{bmatrix} I-A & -B \\ D & -I+S \end{bmatrix} \begin{bmatrix} x \\ w \end{bmatrix} = \begin{bmatrix} c \\ c^+ \end{bmatrix}$$

with

$$A = [a_{kK}] = \left[\frac{X_{kK}}{X_K}\right]$$ input-output coefficient

$$D = [d_{hK}] = \left[\frac{W_{hK}}{X_K}\right]$$ quantity of emission $h = 1\ldots l$ per output unit (joint product)

$$B = [b_{kH}] = \left[\frac{x_{kH}}{W_k}\right]$$ input of activity $H = 1\ldots l$ per unit of abated emissions provided by sector k

$$\Sigma = [\sigma_{hH}] = \left[\frac{W_h}{W_H}\right]$$ waste product $h = 1\ldots l$ caused per output unit W_H with $H = 1\ldots l$

Here σ_{hH} denotes the quantity of wastes h generated in the abatement of a unit of waste product H. If the d_{hK} coefficients are negative, then they denote the use of a waste product as an input. Finally, c is final demand of tolerated emissions.

The level of emissions can be determined, given levels of c and c^+. It is given by the vector w:

$$\begin{bmatrix} x \\ w \end{bmatrix} = \begin{bmatrix} I-A & -B \\ D & -I-\Sigma \end{bmatrix} \begin{bmatrix} c \\ c^+ \end{bmatrix}$$

Assuming that not only production but also consumption brings about wastes, the wastes are determined by $w^+ = D^+ c^+$, where $D^+ = d^+_{hK}$ denotes emission h occurring per unit of final demand k. Then the total emission vector w of production and consumption may be written as

$$\bar{w} = [D \mid \Sigma] \begin{bmatrix} x \\ w \end{bmatrix} + D^+ c$$

Using this approach, the emissions of an economy can be determined. The sum of the columns depicts the interdependency between product prices and value added. For a given value added, the price of the products can be calculated. This also applies to the calculation of prices of abatement activities. Assume that the producers have to abate part of a total waste. If one transforms the waste products that appear as joint products into a value factor, then the price change of the goods resulting from this political measure can be determined.

Let t_{hK} denote the part of the pollutant h that is caused by industry K and that also has to be abated by it. Then we have

$$\left[\begin{array}{c|c} I-A' & -D't \\ \hline -B' & I-\Sigma't \end{array}\right] \begin{bmatrix} p_1 \\ p_2 \end{bmatrix} = \begin{bmatrix} \omega_1 \\ \omega_2 \end{bmatrix}$$

with p_1 and p_2 as price vectors of the activities x and w and ω_1 and ω_2 as the added values of these activities.

Leontief comes to the conclusion that waste-abatement sectors contribute to the production of waste products by their demand for inputs from other sectors and through the stimulation of demand itself. Here is how we evaluate this multiplier of pollution abatement. Assume that the vector of the waste products w that is connected with a given output vector X is given. If the costs per unit of alternative waste-abating processes are known, then the minimal costs of the waste abatement can be calculated in a programming model.

Let l represent the abatement costs without considering the generation of pollutants in abatement. Let l' represent abatement costs that also take into account the fact that pollutants are generated in abatement. Then the expression l' / l is the desired multiplier. Also, a waste-income multiplier can be calculated. This multiplier denotes the quantity of waste products per dollar income of a sector (not as in Leontief's study, where it is per unit of final demand). Such a multiplier could be relevant with respect to studies of industrialization.

In a similar way, input-output analysis with fixed coefficients has been used to estimate embodied pollutant emissions and the embodied energy intensity; that is, the total emissions and energy required directly and indirectly by the economy in supporting one unit of monetary value of final demand (Imura et al. 1995). Moreover, input-output modeling has been applied to estimate primary energy and greenhouse gas embodiments in goods and services (Lenzen 1998). The input-output model has also been used in life-cycle assessment to quantify the environmental implications of alternative products and processes, tracing pollution discharges and resource use through the chain of producers and consumers (Lave et al. 1995). Hawdon et al. (1995) showed how a number of the complex interrelationships between energy, the environment, and economic welfare could be investigated with an input-output model of the UK, using pollution emission coefficients and a European sulfur deposition vector. Proops et al. (1993) investigated how economic structural change has brought about increased atmospheric concentrations of CO_2, and how economic structural change may be used to reduce CO_2 emissions over the next 20 years by input-output analysis.

Another application of the input-output approach is to study the impact of an emission tax or of other policy instruments on the price vector of an economy. This uses the dual of the input-output approach being based on the columns of the input-output table. In this way, the price effects of carbon tax can be calculated (Common and Salma 1992b).

With a similar approach, Heister et al. (1991) estimate the short-run intersectional price effects of taxes on CO_2 or of CO_2 certificates. Distributive effects of CO_2 taxes on the British economy are analyzed by Symons et al. (1990).

As a general critique, input-output models can only be considered as a first step for analyzing interdependencies in the environment. Functional relationships are likely to be nonlinear. Threshold effects and irreversibility are relevant in the environmental context. Linear models cannot deal with them.

Appendix 2B: Applied General Equilibrium Models

Input-output models are extended into applied general equilibrium models by explicitly introducing a supply and demand system, by integrating nonlinear relationships, and by taking into account dynamic properties and aspects of the environmental system including the accumulation of pollutants, the depletion of resource stocks, capital accumulation, and technological change. Quite a few publications exist on applied general equilibrium models (Adkins and Garbaccio 1999; Bergman and Henrekson 2003; Boehringer and Löschel 2003; Conrad 2002a; Kainuma et al. 1999; Shoven and Whalley 1992).

A common procedure in applied general equilibrium models is to "calibrate" the parameters of the model to data from a single year, for instance by using input-output matrices. In more developed versions, the parameters of the behavioral or structural equations are estimated econometrically. The model can represent partial equilibrium models that take some aspects as given and more comprehensive models in which most of the processes are endogenous. Models explicitly model producer and consumer behavior, include the export sector and import substitution, and factor markets and abatement technologies (Conrad 2002a). A basic model with econometric construction is the Jorgenson-Wilcoxen model (1990b) in which the abatement costs are explicitly introduced and in which the impact of environmental policy on economic growth is estimated. Jorgenson and Wilcoxen (1990c) estimate separate models of production for 35 industrial sectors of the US economy explicitly taking into account substitution of pollutants. In a separate disaggregate model of the household sector with 672 types of households, consumer behavior is estimated econometrically. Then, both the production and the consumer models are incorporated into an intertemporal equilibrium model. Finally, the impact of environmental regulation on growth is analyzed.

Quite a few applied general equilibrium models analyze the impact of CO_2 Policies. MERGE (Model for Evaluating Regional and Global Effects of Greenhouse Gas Reductions) is a general equilibrium model which provides a framework for thinking about climate change management proposals (Manne et al. 1995; Manne and Richels 2003). Another example is CETA, which presents worldwide economic growth, energy consumption, energy technology choice, global warming, and global warming costs over a time horizon of more than 200 years (Peck et al. 1995). McKibbin et al. (1998a) developed the G-Cubed model, a multi-country, multi-sector intertemporal general equilibrium model for studying a variety of topics such as greenhouse gas policy, trade liberalization, tax policy, and macroeconomic policy. A programming environment for economic equilibrium analysis has also been developed by Rutherford (1994, 1997). These models have been used to analyze the impacts of climate policies (Bernstein et al. 1998; Jacoby et al. 1998; Kainuma et al. 1999; Manne 1998; McKibbin et al. 1998b).

The GREEN (*G*ene*R*al *E*quilibrium *EN*vironmental) model of the OECD (Burniaux et al. 1992a,b; Nicoletti 1992; Oliveira-Martins et al. 1992a,b) contains 12 detailed regional submodels, namely 4 OECD regions – the United States, Japan, EC, and other OECD – and 8 non-OECD regions – the former USSR, the Central and Eastern-European Countries, China, India, the Energy-Exporting LDCs, the Dynamic Asian Economies, Brazil, and the Rest of the World. The model includes 11 production sectors, 15 factors of production, and 4 consumption goods. The GREEN model runs over a period of 65 years to 2050. The model has a sequential structure in that the equilibrium in each period can be calculated independently, but the equilibrium of a given period will influence the next period. Capital accumulation and resource extraction are modeled as an intertemporal phenomenon. Whereas the GREEN model does not portray the intertemporal mechanics of consumption and savings, other applied general equilibrium models also explicitly consider decisions of the households (Jorgenson and Wilcoxen 1990; McKibbin et al. 1992).

Another applied general equilibrium model is the DART (Dynamic Applied Regional Trade) model (Klepper et al. 2003). It is a multi-region, multi-sector recursive dynamic Computed General Equilibrium model of the world economy. For instance, for the analysis of the EU emission trading system it is calibrated to an aggregation of 16 regions, illustrating the 9 countries or group of countries of the European Union including the accession countries of Eastern Europe and the other 7 world regions. The economy in each region is disaggregated into 12 sectors and is modeled as a competitive economy with flexible prices and market clearing. A representative consumer, a representative producer in each sector, and regional governments are the agents. All regions are connected through bilateral trade flows. The DART model has a recursive-dynamic structure solving for a sequence of static one-period equilibria. The major exogenous drivers are the rate of productivity growth, the savings rate, the rate of change of the population, and the change in human capital. The model is calibrated to the GTAP5 database that represents production and trade data for 1997. A similar model with trade and capital mobility is used by Springer (2002) to evaluate the impact of CO_2 reductions on the regions of the world.

Applied general equilibrium models have been used to measure welfare costs of climate change policies (Bernard and Vielle 2003; Conrad 2002a), to discuss policy relevant post-Kyoto scenarios (Böhringer and Löschel 2005), the double dividend hypothesis, and tradable permits for CO_2 (Conrad 2002b). Applied general equilibrium models can also have a two-way link between the economy where on the one hand the economy affects environmental quality and where on the other hand environmental quality influences economic variables, such as labor productivity.

Part II
Static Allocation Aspect

3 Production Theory and Transformation Space

In the following four chapters, the static allocation aspect is analyzed. We study production theory, assuming emissions as joint outputs of production and treating environmental quality as a variable in the production set (chapter 3). After defining the production possibilities, we study which prices should be set in order to reach optimal results with respect to a welfare criterion. Also, we analyze whether optimality can be attained in a competitive equilibrium when environmental quality is taken into consideration (chapter 4). In chapter 5, we present the public-goods approach to environmental allocation. Benefitcost analysis, the Lindahl solution, and institutional mechanisms which reveal individual preferences are discussed. Whereas the public-goods approach starts from the assumption that environmental quality cannot be attributed to individuals, the property-rights discussion stresses the point that the introduction of property rights may solve the allocation problem (chapter 6).

Production Theory

We consider a simplified two-sector economy characterized by pollutants which are generated as joint products of output and then emitted into the environment (emissions). For simplifying purposes, we assume that there is only one type of pollutant generated by the two sectors:[1]

$$S_i^p \geqslant H_i(Q_i) \quad H_i' > 0, H_i'' \geqslant 0 \text{ for } i = 1, 2 \tag{3.1}$$

This emission function assumes that at a given technology the quantity of pollutants S_i^p increases proportionally or progressively with output Q_i, but excludes the case in which the quantity of pollutants increases regressively. Figure 3-1a depicts the emission function for the cases $H_i'' = 0$ (linear curve) and $H_i'' > 0$ (strictly convex curve).

The production function is characterized by a declining marginal productivity and does not distinguish among different production factors. Rather, for simplicity, we assume only one type of resource R (compare Fig. 3-1b):

[1] The inequality sign allows for the case where the generation of pollutants is inefficient in the sense that more pollutants are generated than necessary. Note, however, that because of the mass-balance concept, emissions are restricted.

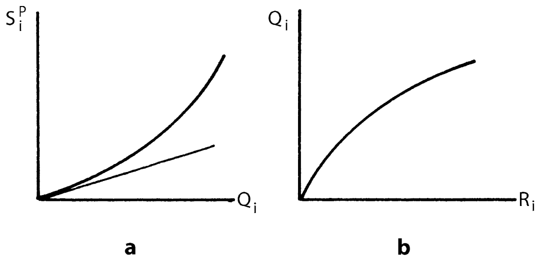

Fig. 3-1. Emission and production functions

$$Q_i \leqslant F_i(R_i) \quad F_i' > 0, F_i'' < 0 \tag{3.2}$$

From Eqs. 3.1 and 3.2 a function results which shows the emissions to be dependent on the resource input:

$$S_i^p = H_i[F_i(R_i)] = Z_i(R_i) \quad Z_i' > 0, Z_i'' \gtreqless 0 \tag{3.1a}$$

This function shows that the pollutants in this approach can also be understood to be joint products of the input. Obviously, a model could be formulated in which Eq. 3.1-a, instead of 3.1, could be used. Note that $Z_i' = H_i' F_i' > 0$.

If one applies the mass-balance concept to the production function, then a concave production function implies a convex emission function. This is explained as follows. Let a and β designate the quantitative content of resources in commodity 1, and let S_1^p be the joint product. Then we have

$$\alpha Q_1 + \beta S_1^p = R_1$$

so that

$$S_1^p = \frac{1}{\beta}(R_1 - \alpha Q_1) = \frac{1}{\beta}[R_1 - \alpha F_1(R_1)] = Z_1(R_1)$$

Because the function F is concave, the emission function Z has to be convex. Thus, the mass-balance concept and a concave production function imply $Z_i'' > 0$. Such a convex emission function is assumed in the following analysis. Note that $Z_i'' = H_i'' F_i'^2 + H_i' F_i''$, so that $Z_i'' > 0$ implies that $H_i'' > 0$.

The pollution-abatement function tells us that pollutants can be reduced by an input of resources in abatement R_i^r, where S_i^r denotes the abated quantities of the pollutants. As with the production function, here a declining marginal productivity is assumed to prevail. The abatement function is specific to each sector, as is the emission function[2]

[2] I do not consider the mass-balance concept in abatement. Note that declining marginal productivities in abatement imply residuals of abatement activities.

$$S_i^r \leqslant F_i^r(R_i^r) \quad F_i^{r'} < 0, F_i^{r''} > 0 \tag{3.3}$$

In reality, pollutants can be abated by different processes. First, pollutants can be reduced by new production technologies. Here I assume a given technology. Second, pollutants can be reduced by filtering and withholding procedures before they actually enter the environmental media. Therefore, one can start from the fact that the abatement technologies are sector-specific. This case is assumed here. Finally, pollutants can be abated even when they are already ambient in the environmental media (water).

The diffusion function in Eq. 3.4 explains the relationship between emissions S_i^p and the quantity of pollutants ambient in the environmental media S.[3] A more precise formulation of the diffusion function should take into consideration the assimilative capacity of the environmental system, that is, its capacity to receive pollutants and reduce them without changing the quality of the environment. The determination of this assimilative capacity (in a river system, for example, the current speed, percentage of oxygen, temperature, and quantity of pollutants) and its temporal variation can be influenced by resource inputs (for example, in-stream aeration of a river system and afforestation). This purification of media (for example, water management) could be introduced into the model by an abatement function which is not specific to a sector (for example, the purification function of a water cooperative). Anyway, since the diffusion problem is not considered further, Eq. 3.4 is utilized solely as an equation for defining pollutants ambient in the environment. In this model, the diffusion function degenerates to a definition; pollutants ambient in the environment are identical to the total quantity of emissions. In the following, the concepts of total emissions and pollutants ambient in the environment are used synonymously because of the nonconsideration of the diffusion problem.

$$S = \sum S_i^p - \sum S_i^r \tag{3.4}$$

The damage function in Eq. 3.5 specifies how pollutants S have an effect on environmental quality. Here the damage function is a physical relationship and does not evaluate environmental quality in monetary terms. In a simple interpretation, Eq. 3.5 may be understood as an index function which defines an index of environmental quality in terms of pollutants. Alternatively, environmental quality may be defined independently of pollutants (for example, amenity of the landscape and stability of ecological systems). Then Eq. 3.5 defines a physical relationship rather than an index function. Besides damage to the public-consumption-good environment, one can imagine other damage functions: Pollutants influence the quality of inputs in production processes, the production processes themselves, almost finished goods (financial losses),

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[3] It is assumed here that pollutants ambient in the environment die away at the end of the period. In chapter 15 this assumption of the immediate decay of the pollutants is removed.

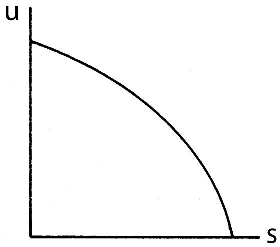

Fig. 3-2. Damage function

and so on. The damage function, shown in Fig. 3-2, considers only environmental damages

$$U \leqslant G(S) \quad G' < 0, G'' < 0 \tag{3.5}$$

A resource restriction limits the production and abatement possibilities of the economy considered:

$$\sum R_i + \sum R_i^r \leqslant \bar{R} \tag{3.6}$$

Transformation Space with Environmental Quality

Equations 3.1 through 3.6 describe the production possibilities of the economy; if one wants to produce more at a given technology with resources being fully utilized, then emissions will increase and the quality of the environment will be reduced. This is due to the fact that, according to the emission function, emissions rise with increasing output. Also, in order to increase production, resources must be withdrawn from abatement. Environmental quality then declines for two reasons: more emissions from increased production and reduced abatement. In contrast, an improvement of environmental quality at a given technology with full utilization of the resources is possible only if more resources are used in abatement and the production of the commodities is reduced. It becomes clear that the central competitive use in the case of environmental pollution exists between the environment as a public-consumption good and as a receptive medium for pollutants.

Figure 3-3 represents graphically the restrictions described in Eqs. 3.1 through 3.6 for a two-commodity economy. The transformation space in Fig. 3-3 illustrates the maximum production possibilities for commodities 1 and 2 and the public good, environmental quality. Restrictions 3.1 through 3.6 may also be expressed by the equation $U = \phi(Q_1, Q_2)$. An important question then, is: What characteristics does the transformation space have? That is, is the function $U = \phi(Q_1, Q_2)$ concave or not (compare Appendix 3 A)?

The following intuitive considerations serve to determine more precisely the form of the transformation space. A more formal treatment is given in Appen-

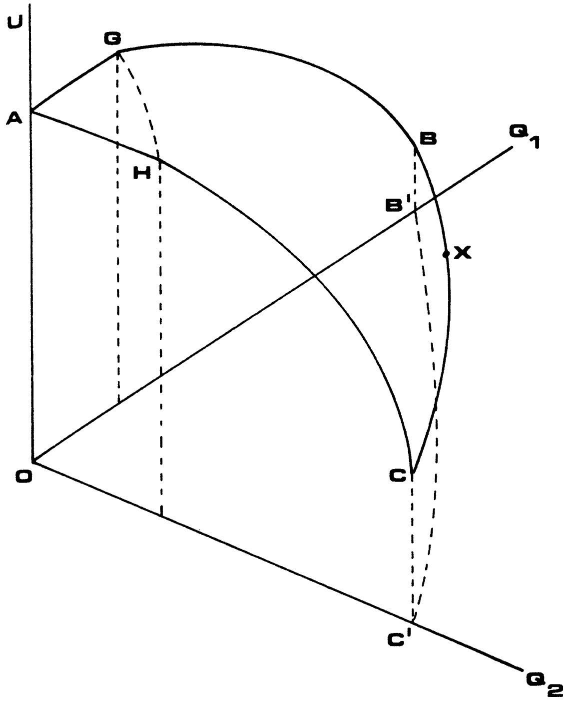

Fig. 3-3. Transformation space with environmental quality

dix 3 A. For simplicity, it is assumed here that only one type of abatement activity exists, and *R3* denotes the resource input in abatement. Moreover, it is assumed that commodity 1 is the pollution-intensive commodity. This can be expressed as

$$H'_1F'_1 > H'_2F'_2 \tag{3.7}$$

Condition 3.7 can be interpreted with the help of Eq. 3.1 a, for $H'_iF'_i$ is the first derivative of the Z function. The term

$$Z'_i = H'_iF'_i = \frac{\partial S^p_i}{\partial Q_i}\frac{\partial Q_i}{\partial R_i}$$

denotes what quantity of emissions occurs if a resource is used in sector i. Thus $H'_iF'_i$ can be interpreted as the marginal propensity of the resource input to pollute. Condition 3.7 states that the marginal propensity of the resource input to pollute in sector 1 is higher than in sector 2. Sector 1 is the pollution-intensive sector. For a more detailed interpretation of Eq. 3.7, compare Siebert et al. (1980, p. 24).

At zero production in both sectors, the maximum environmental quality (*OA* in Fig. 3-3) is reached, that is, the original natural condition. Let $Q_2 = 0$ and expand the production of commodity 1. Then one can imagine a resource allocation (R_1, R_3) such that all pollutants occurring in the production of commodity 1 are abated (distance *AG* in Fig. 3-3). Analogously, *AH* indicates those production quantities of commodity 2, when $Q_1 = 0$, at which the environmental quality remains maximal. Except for the curve *GH*, the horizontal roof represents a situation with maximum environmental quality and underemployment.

Expand the production of commodity 1 at point *G* for $Q_2 = 0$ by 1 unit. Then the quantity of emissions increases progressively owing to the fact that $H_1'' > 0$. Because environmental quality decreases overproportionally with increased emissions, environmental quality has to fall overproportionally as a consequence of the increase in production of commodity 1. With an increase in production of commodity 1, additional resources are used in production. Since these resources must be withdrawn from abatement, the quantity of abated emissions falls (an environmental quality declines). We know that as a result of each unit of input withdrawn from abatement, the unabated emissions increase overproportionally. This is explained by the decreasing marginal productivity in abatement. Finally, according to the law of declining marginal returns, each additional unit of commodity 1 produced requires an increasingly greater input of resources. Consequently, for a shift from *G* to *B*, the quantity of pollutants has to increase progressively as inputs are reallocated from abatement to the production of commodity 1. Therefore, environmental quality has to decrease progressively. The curve *GB* is concave. The concavity of curve *GB* can also be shown formally (Appendix 3A).

The distance BB' denotes that quality of the environment which results from a total specialization in the production of commodity 1, given full employment and no abatement. The distance CC' represents that quality of the environment which corresponds to a total specialization in commodity 2 with no abatement. And $CC' > BB'$ reminds us that commodity 1 is the pollution-intensive commodity.[4]

Define $\alpha = Q_1/Q_2$ and hold a constant. Consider a point on the curve *GH*. A unit of resources is withdrawn from abatement and put into the production of commodities 1 and 2 with the quantitative relation α of both commodities remaining constant. The quantity of emissions rises progressively in both sectors; in abatement, the quantity of unabated emissions decreases progressively, since the marginal productivity of disposal activities increases with a lower factor input. A reallocation of the resources in favor of production, given a constant proportion of commodities a, thus causes the emissions to

[4] Note that the pollution intensity of sectors is defined in terms of marginal propensities. On the relation of marginal and average pollution intensities, compare Siebert et al. (1980).

rise progressively. At the same time, marginal productivity increases underproportionally in production. The curve of the transformation space, for α held constant, is concave (compare Eq. 3 A.12).

Curve BC represents the transformation problem for the case of resources not being used in abatement ($R_3 = 0$). The projection of curve BC into the Q_1 Q_2 plane, that is, the curve $B'C'$, is the traditional transformation curve. In a situation without environmental policy, the economy is located on curve BC. Point X on the transformation curve, that is, the vector of goods and thus the factor allocation $\{R_1, R_2\}$, is determined by the relative price p_2/p_1.

This intuitive reasoning and formal analysis show that the transformation space is concave. There is a tradeoff between the production of commodities and the provision of environmental quality. If one wants a higher output, the quality of the environment must be reduced. And if one wants the quality of the environment to be improved, output has to be reduced.

Variables Affecting the Transformation Space

This analysis suggests that the form of the transformation space is affected by the following variables: resource endowment of the economy, pollution intensity of the two sectors, and productivity in production and abatement.

In Fig. 3-4a a case is presented in which sector 1 is pollution-intensive whereas sector 2 produces no pollutants at all. In this case, sector 2 can produce without negatively affecting environmental quality. Point C depicts a situation in which all resources are used in the production of commodity 2 and no environmental degradation occurs.

In Fig. 3-4b we have assume that curve GB shifts outward to GB''. This can be due to technical progress in the production of commodity 1, in the emission function (reduced emissions), or in abatement of sector 1. It is conceivable

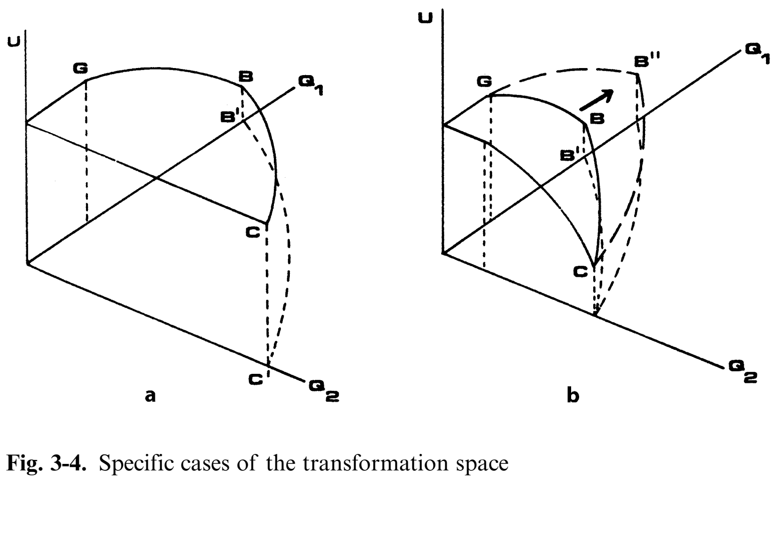

Fig. 3-4. Specific cases of the transformation space

that, because of technical progress, sector 1 is no longer the pollution-intensive sector. Another condition not depicted in Fig. 3-4 is an increase in resource endowment. In such a case, the whole transformation space shifts outward, including curve *GH* in Fig. 3-3.

In reality, we may also observe that pollutants have a negative impact on production. For example, particulates from mining may reduce the productivity of nearby citrus trees. Then the production function shown in 3.2 has to be redefined as

$$Q_i = F_i(R_i, S) \quad \text{with} \quad F_{iS} < 0, F_{iSS} < 0 \tag{3.8}$$

Here $F_S < 0$ indicates that pollutants affect production negatively; that is, pollutants have a negative productivity effect. And $F_{iSS} = dF_{iS}/dS < 0$ says that the negative productivity will become smaller in absolute terms. If Eq. 3.8 holds true, increased production means not only a decline in the quality of the environment, but also a reduction of output since pollutants will have a negative impact on output. With a larger stock of pollutants, the transformation space may tend to contract (curve *GB″* in Fig. 3-5). From Eq. 3 B.4 in the appendix we have

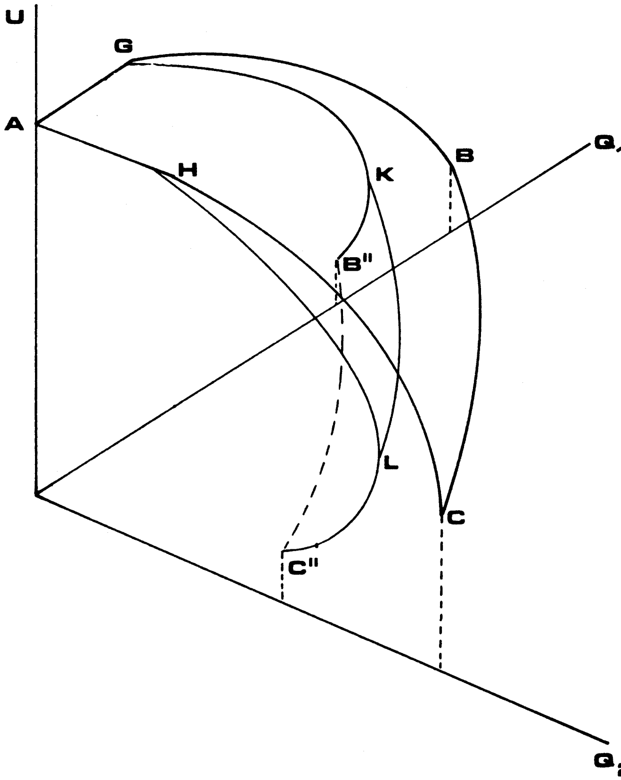

Fig. 3-5. Transformation space with negative externalities

$$\frac{\partial U}{\partial Q_i} \lesseqgtr 0 \Leftrightarrow \phi_{1S} + \phi_{2S} \gtreqless \frac{1}{F_3'} \tag{3.9}$$

By defining an inverse to the production function 3.8 we get

$$R_i = \phi_i(Q_i, S)$$

Then ϕ_{iS} indicates the inputs required to compensate for the effect of negative productivity caused by one unit pollutant, if output in sector i is to be kept constant. The term $\phi_{1S} + \phi_{2S}$ denotes total inputs required to keep output constant in both sectors. The right hand side of inquality 3.9 denotes resources used for abating one unit of pollutant. If the inputs required to compensate for the negative productivity effect caused by one unit of pollutant are smaller than those required for abating one unit of pollutant, then $\partial U/\partial Q_i < 0$, that is, curve GKB'' in Fig. 3-5 has a negative slope. If more resources are needed in order to compensate for the negative productivity effect caused by one unit of pollutant than those required for its abatement, curve GKB'' will have a positive slope. When S rises, the absolute value of ϕ_S^i rises. Also, F_3' will fall and $1/F_3'$ will rise.

Compare the transformation space $AGB''C''H$, in which negative externalities in production exist (Eq. 3.8), with the case $AGBCH$, in which no negative externalities in production exist (Eq. 3.2). One can expect that negative externalities in production will shift the transformation space inward. Also, the transformation space may not be concave in the case of negative externalities. This may raise serious theoretical questions since normally one assumes the concavity of the transformation space when analyzing the existence of equilibrium or the properties of optimality in a state of competitive equilibrium.[5] Note that points G and H are identical in Figs. 3-3 and 3-5 since there is no negative productivity effect at maximal environmental quality.

The properties of the transformation space are affected by the intensity of the negative productivity effect of pollutants. If the negative productivity is small or negligible, then the transformation space will not curve inward. If sector 1 is strongly affected by pollutants, then the inward bend will be stronger for sector 1 than for sector 2.

Note that $\partial U/\partial Q_i > 0$ holds true in section $C''B''KL$. This means that environmental quality has positive opportunity costs. One can increase environmental quality and production at the same time. There is no tradeoff between environmental quality and private outputs.

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[5] A more detailed analysis is given in Siebert (1982g).

An Alternative Approach of Production Theory

An alternative approach in the description of the production properties of an economy is to integrate Eqs. 3.1, 3.2, and 3.3 into a production function (Pethig 1979)

$$Q_i = F_i(\tilde{R}_i, \tilde{S}_i) \tag{3.10}$$

In Eq. 3.10, resource input $\tilde{R}_i$ is defined as $\tilde{R}_i = Ri + R_i^r$; that is, it indicates total resources used by sector 1 without distinguishing between resources used for production and those used for abatement. Similarly, $\tilde{S}_i$ is defined as $\tilde{S}_i = S_i^p - S_i^r$, that is, net emissions. In Eq. 3.10, net emissions are interpreted as a factor of production with $F_{iS} > 0$. And $\tilde{S}_i$ can be interpreted as being an assimilative service which the environment provides for use by firms. Equation 3.10 does not tell anything about which quantities of resources are used for production or for abatement. Also, there is no information about gross emissions S_i^p or the abated emissions S_i^r. The concept underlying Eq. 3.10 assumes that production, emission, and abatement technologies can be described as technological relationships allowing substitution between the resource inputs $\tilde{R}_i$ and $\tilde{S}_i$. Note that $\tilde{R}_i$, can be interpreted as a vector for different types of inputs, such as labor and capital. Also, observe that $\tilde{S}_i$ in Eq. 3.10 indicates net emissions of sector i, not the stock of pollutants in the environment. Equation 3.10 can easily be extended in order to allow for a negative productivity effect emanating from a pool of pollutants by introducing a variable S with $F_S < 0$.

The law of conservation of matter represents a restriction for Eq. 3.10. In terms of weight, the sum of regular output and net emissions cannot surpass the input. Consequently, net emissions must be restricted. For instance, a monotonic function φ_i may restrict net possible emissions:

$$\tilde{S}_i \leqslant \varphi_i(\tilde{R}_i) \tag{3.11}$$

Equation 3.11 specifies the input space of the production function. Assume that Eq. 3.11 is linear. Then the production technology in 3.10 and 3.11 can

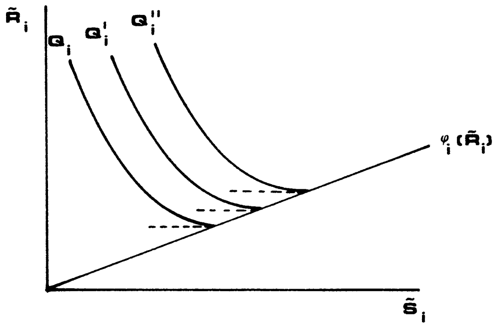

Fig. 3-6. Production function with emissions as input

be described as in Fig. 3-6. Note that $F_{iS} > 0$ is assumed for $\tilde{S}_i < \varphi_i(\tilde{R}_i)$ and $F_{iS} = 0$ for $\tilde{S}_i = \varphi_i(\tilde{R}_i)$; that is, the assimilative capacity of the environment has a zero productivity if the maximum amount of net possible emissions is used. In Fig. 3-6 the isoquants indicate the possibilities for substitution between the inputs $\tilde{R}_i$ and $\tilde{S}_i$.

Although in this approach one does not explicitly consider abatement activities, it has the advantage of lending itself to traditional production theory. For instance, once a price for pollutants is introduced, traditional microeconomic results can be reinterpreted with respect to environmental problems. For an alternative approach including the materials balance, abatement, and nonlinear production, see Pethig (2006).

Appendix 3A: Properties of the Transformation Space

The transformation space $U = \phi(Q_1, Q_2)$ is concave if $d^2 U < 0$, that is, if the Hessian matrix H is negative definite:

$$H = \begin{bmatrix} \frac{\partial^2 U}{\partial Q_1^2} & \frac{\partial^2 U}{\partial Q_1 \partial Q_2} \\ \frac{\partial^2 U}{\partial Q_2 \partial Q_1} & \frac{\partial^2 U}{\partial Q_2^2} \end{bmatrix} \tag{3 A.1}$$

The Hessian matrix is negative definite if $| H_1 | = \partial^2 U/\partial Q_1^2 < 0$ and if $| H_2 | = | H | > 0$.

In order to analyze the concavity of the transformation space, I assume, for simplicity, that only one abatement activity exists. Then the problem is defined by

$$\begin{aligned} S &= H_1(Q_1) + H_2(Q_2) - S^r \\ Q_i &= F_i(R_i) \quad \text{or} \quad R_i = F_i^{-1}(Q_i) \\ S^r &= F_3(R_3) \\ \bar{R} &= R_1 + R_2 + R_3 \end{aligned} \tag{3 A.2}$$

Substitution yields

$$U = G[H_1(Q_1) + H_2(Q_2) - F_3(\bar{R} - R_1 - R_2)] \tag{3 A.3}$$

Now, we have[1]

[1] $\frac{dF_3'}{dQ_1} = \frac{dF_3'}{dR_3}\frac{dR_3}{dR_1}\frac{dR_1}{dQ_1} = -F_3''\frac{1}{F_1'} > 0$ and $\frac{dF_1'}{dQ_1} = \frac{dF_1'}{dR_1}\frac{dR_1}{dQ_1} = F_1''\frac{1}{F_1'} < 0$

$$\frac{\partial U}{\partial Q_1} = G'\left(H'_1 - F'_3\frac{dR_3}{dQ_1}\right) = G'\left(H'_1 - F'_3\frac{dR_3}{dR_1}\frac{1}{F'_1}\right)$$
$$= G'\left(H'_1 + \frac{F'_3}{F'_1}\right) < 0 \qquad (3\text{ A.4})$$

and

$$\frac{\partial^2 U}{\partial Q_1^2} = G''\frac{dS}{dQ_1}\left(H'_1 + \frac{F'_3}{F'_1}\right) + G'\left[H''_1 + \frac{F'_1(dF'_3/dQ_1) - F'_3(dF'_1/dQ_1)}{F'^2_1}\right]$$
$$= G''\left(H'_1 + \frac{F'_3}{F'_1}\right)^2 + G'\left[H''_1 + \frac{1}{F'^2_I}\left(-F''_3 - \frac{F'_3 F''_I}{F'_1}\right)\right] < 0 \qquad (3\text{ A.5})$$

Define $Ai = H'_i + F'_3/F'_i > 0$, $E_i = G'(H''_i - F'_3F''_i/F'^3_i) < 0$, and D $= G'F''_3/(F'_iF'_2) > 0$. Then Eq. 3A.5 becomes

$$\frac{\partial^2 U}{\partial Q_1^2} = G''A_1^2 + E_1 - \frac{DF'_2}{F'_1} \qquad (3\text{ A.6})$$

The minor H_1 is negative. It follows from Eq. 3A.6 that curve *GB* in Fig. 3-3 is strictly concave. Analogously, we obtain $\partial U/\partial Q_2 < 0$ and $\partial^2 U/\partial Q^2_2 < 0$. We have (for constant Q_1 and constant R_1)

$$\frac{\partial^2 U}{\partial Q_1 \partial Q_2} = \frac{\partial[G'[S](H'_1 + F'_3/F'_1)]}{\partial Q_2}$$
$$= G''\frac{dS}{dQ_2}\left(H'_1 + \frac{F'_3}{F'_1}\right) + \frac{G'}{F'_1}\frac{dF'_3}{dR_3}\frac{dR_3}{dR_2}\frac{dR_2}{dQ_2}$$
$$= G''\left(H'_2 + \frac{F'_3}{F'_2}\right)\left(H'_1 + \frac{F'_3}{F'_1}\right) - \frac{G'}{F'_1}\frac{F''_3}{F'_2}$$
$$= G''A_1A_2 - D < 0 \qquad (3\text{ A.7})$$

Equations 3A.6 and 3A.7 are not yet sufficient to establish that $H_2 > 0$ as defined in Eq. 3A.1. The first term of H_2 is positive, the second is negative. Only if the product of the cross derivatives as defined in Eq. 3A.7 is smaller than the product of the derivatives as defined in Eq. 3A.6, will the transformation function be concave.

The Arrow-Enthoven theorem makes less stringent demands for the existence of a global maximum. If the target function is concave, then the quasi-convexity of every restriction is sufficient (thus quasi-concavity, too).[2] The

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[2] A.-C. Chiang, Fundamental Methods of Mathematical Economics, 3rd ed. (New York: McGraw-Hill, 1984).

production, abatement, and damage functions are concave and thereby quasi-concave too. The emission function is a monotonic function of a variable and thereby quasi-concave as well as quasi-convex. The resource restriction is linear. Consequently, the Arrow-Enthoven conditions are fulfilled. Thus the condition of concavity is more restrictive than the condition for a quasi-concavity.

An alternative (more intuitive) approach for verifying the concavity of $U = \phi(Q_1, Q_2)$ runs as follows. The transformation space $U = \phi(Q_1, Q_2)$ is concave if every restriction is concave. The production, abatement, and damage functions are concave. The resource restriction is linear and hence concave (and convex). The emission function is linear for $H_i'' = 0$ (and thus concave and convex). If we assume that $H_i'' = 0$, the transformation space $U = \phi(Q_1, Q_2)$ is concave because all single restrictions which define it are concave.

The concavity of the transformation space implies that a cut through the transformation space for a given U, that is, a given level of pollutants S, will also be concave. We have

$$\bar{S} = H_1(Q_1) + H_2(Q_2) - F_3(R_3)$$
$$d\bar{S} = 0 = H_1' dQ_1 + H_2' dQ_2 - F_3'(-dR_1 - dR_2)$$
$$0 = H_1' dQ_1 + H_2' dQ_2 + \frac{F_3'}{F_1'} dQ_1 + \frac{F_3'}{F_2'} dQ_2$$
$$\frac{dQ_1}{dQ_2} = -\frac{H_2' + F_3'/F_2'}{H_1' + F_3'/F_1'} = -\frac{A_2}{A_1} < 0 \tag{3 A.8}$$

so that the rate of transformation corresponds to the relation of marginal costs (including costs of abatement):

$$\frac{d^2 Q_1}{dQ_2^2} = -\frac{1}{A_1^2}\left\{A_1\left[H_2'' + \frac{1}{(F_2')^2}\left(F_2'\frac{dF_3'}{dQ_2} - F_3'\frac{dF_2'}{dQ_2}\right)\right]\right.$$
$$\left.\cdot\left[\frac{dH_1'}{dQ_2} + \frac{1}{(F_1')^2}\left(F_1'\frac{dF_3'}{dQ_2} - F_3'\frac{dF_1'}{dQ_2}\right)\right]\right\} \tag{3 A.9}$$

We have[3]

[3] $\frac{dF_3'}{dQ_2} = \frac{dF_3'}{dR_3}\frac{dR_3}{dR_2}\frac{dR_2}{dQ_2} = F_3''\frac{dR_3}{dR_2}\frac{1}{F_2'} = F_3''\frac{1}{F_2'}\left(-\frac{dR_1}{dR_2} - 1\right)$

$\frac{dH_1'}{dQ_2} = \frac{dH_1'}{dQ_1}\frac{dQ_1}{dQ_2} = H_1''\frac{dQ_1}{dQ_2} < 0$ and $\frac{dF_2'}{dQ_2} = F_2''\frac{1}{F_2'}$ and

$\frac{dF_1'}{dQ_2} = \frac{dF_1'}{dR_1}\frac{dR_1}{dR_2}\frac{dR_2}{dQ_2} = \frac{F_1''}{F_2'}\frac{dR_1}{dR_2}$

$$\frac{d^2Q_1}{dQ_2^2} = -\frac{1}{A_1^2}\left\{A_1\left[H_2'' + \frac{1}{(F_2')^2}\left(-F_3''\frac{F_3'F_2''}{F_2'}\right)\right]\right.$$
$$-A_2\left[\frac{dH_1'dQ_1}{dQ_1dQ_2} + \frac{1}{(F_1')^2}\left(-\frac{F_3''F_1'}{F_2'} - \frac{F_3'F_1''}{F_2'}\frac{dR_1}{dR_2}\right)\right]$$
$$\left.-A_1F_3''\frac{1}{(F_2')^2}\frac{dR_1}{dR_2} + A_2F_3''\frac{1}{F_1'F_2'}\frac{dR_1}{dR_2}\right\} \qquad (3\text{ A.10})$$

This implies

$$\frac{d^2Q_1}{dQ_2^2} < 0:\ -A_1\frac{F_3''}{F_2'} + A_2\frac{F_3''}{F_1'} - A_1\frac{F_3''}{F_2'}\frac{dR_1}{dR_2} + A_2\frac{F_3''}{F_1'}\frac{dR_1}{dR_2} > 0$$
$$\frac{d^2Q_1}{dQ_2^2} < 0:\ -\left(1 + \frac{dR_1}{dR_2}\right)\frac{F_3''}{F_1'F_2'^2}(H_1'F_1' - H_2'F_2') > 0$$

$$\frac{d^2Q_1}{dQ_2^2} < 0:\ H_1'F_1' \gtrless H_2'F_2' \qquad (3\text{ A.11a})$$

$$1 + \frac{dR_1}{dR_2} \gtrless 0 \qquad (3\text{ A.11b})$$

Assume that sector 1 is the pollution-intensive sector, that is, $H'_1 F'_1 > H'_2 F'_2$. Then $dR_1/dR_2 < -1$ implies that the use of one additional unit of resource in the less pollution-intensive sector will not require that sector 1 loses one unit of resource. This is due to the fact that a shift toward the less pollution-intensive sector, for given S, requires less resources in abatement. This reduction in abatement enables more resources to be made available for sector 2. If sector 2 is assumed to be the pollution-intensive sector, one additional unit of output by sector 2 requires that sector 1 loses more than one unit of resource. This follows because additional resources have to be put into abatement in order to keep a given level of pollution S.

Define a constant relation $\alpha = Q_1/Q_2$. Then Eq. 3-A.2 simplifies to

$$U = G[H_1(\alpha Q_2) + H_2(Q_2) - F_3(\bar{R} - R_1 - R_2)] \qquad (3\text{ A.12})$$

It can easily be shown that this curve is concave.[4]

[4] Compare H. Siebert (1978b, p. 55).

Appendix 3B: Transformation Space with Negative Productivity Effect

Assume a production function

$$Q_i = F_i(R_i, S) \quad \text{with} \quad F_{iS}<0, F_{iSS}<0 \tag{3 B.1}$$

The inverse defines the input requirements

$$R_i = \phi(Q_i, S) \tag{3 B.2}$$

where the properties of the inverse are determined by the assumption on the production function. Substituting Eq. 3 B.2 into the system of Eqs. 3.1 and 3.3 through 3.6, we have

$$U = G\{\sum H_i(Q_i) - F_3[\bar{R} - \sum \phi_i(Q_i, G^{-1}(U))]\} \tag{3 B.3}$$

Equation 3-B.3 implicitly defines a function between U and Q1; that is, it defines the transformation space. Equation 3 B.3 should be compared with Eq. 3A.3 which defines the transformation space for the traditional production function. From 3 B.3 we have

$$\frac{\partial U}{\partial Q_i} \lesseqgtr 0: \ \phi_{1S} + \phi_{2S} \lesseqgtr \frac{1}{F'_3} \tag{3 B.4}$$

The concavity of the transformation space for this case is not analyzed here further. However, compare Siebert (1982g).

4 Optimal Environmental Use

The transformation space analyzed in chapter 3 describes the production possibilities of two private goods and the public good "environmental quality" All combinations of the transformation space can be attained. But which set of outputs should be sought? In order to answer this question, we must introduce value judgments that eventually allow us to determine the desired set of outputs.

Criteria for Optimality

For our purposes it is sufficient to review briefly the three most often used optimality criteria.[1]

Koopmans Efficiency

An output is Koopmans-efficient if, with given technology and given resources, the ith output cannot be increased for given quantities of all other commodities j. For our problem, this means that an allocation is not efficient if, for a given output Q_1 and Q_2, environmental quality can be increased. Similarly, an allocation is not Koopmans-efficient if, for a given environmental quality, the output of one of the commodities can be increased without having to decrease the output of the other. Inefficient allocations lie inside the transformation space in Fig. 3-3. Koopmans efficiency requires that we produce on the transformation space in order not to waste resources.

Social-Welfare Function

It is assumed that society has a welfare function

$$W = W(C_1, C_2, U) \tag{4.1}$$

[1] On welfare criteria, compare Mas-Colell et al. (1995). The "maximin" criterion suggested by Rawls (1971) has received considerable attention in the analysis of resource use, especially in an intertemporal context. Compare Fisher (1981) p. 71. On ethical issues also compare Kneese and Schulze (1985).

or that a politician knows the welfare function of the society. In such a welfare function, environmental quality is an independent variable. In Fig. 3-3, one can imagine such a welfare function being represented by a three-dimensional indifference lid. Higher indifference lids represent higher levels of welfare. The optimizing problem consists of finding the highest indifference level for a given transformation space. The optimal point will be reached were an indifference lid is tangential to the transformation space. Mathematically, the properties of the optimum can be determined by maximizing Eq. 4.1 subject to constraints 3.1 through 3.6, which define the transformation space.

Pareto Optimality

The Pareto criterion does not start from a social-welfare function; rather, it assumes individual utility functions in which utility is defined by an ordinal measure, that is, the utility function is a utility index function. A situation is Pareto-optimal if, for constant utility of all individuals except j, the utility of individual j cannot be increased. A situation is not Pareto-optimal if, for constant utility of all individuals except j, the utility of individual j can be increased.

To simplify the problem of environmental allocation, we assume an economy consisting of two individuals, 1 and 2. The utility of both individuals depends on the quantities consumed of the two private goods and on environmental quality. Variable C_i^j denotes the quantity of commodity i consumed by individual j. Note that, unlike the consumption quantities of the private goods i, U does not have a personalized superscript; environmental quality is a public good:[2]

$$W^j = W^j(C_1^j, C_2^j, U) \tag{4.2}$$

Other variables may also enter into the utility function (or the social-welfare function) such as employment, price-level stability, and equity. In this chapter, we use the Pareto criterion as a guideline for optimal allocation. In chapter 5 we see that the choice of the value criterion also has important institutional aspects. For instance, the question arises by which mechanism a social-welfare function can be aggregated from individual preferences or by which institutional arrangement individual evaluations can be revealed.

[2] Alternatively, we could define U^j as the environmental quality used by individual j. Then we would have to observe the restraint $U^1 = U^2 = U$.

Optimization Problem

For simplicity, in our economy consisting of two individuals we apply the Pareto criterion and maximize the utility of individual 1, subject to the utility of individual 2 remaining constant (Eq. 4.2). The utility that can be obtained by individual 1 is restricted not only by the condition that the utility of individual 2 has to remain constant but also by the constraint posed by the transformation space (Eqs. 3.1 through 3.6). Finally, the quantity demanded by the two individuals equals total demand

$$C_i = \sum_j C_i^j \tag{4.3}$$

and total demand for a commodity cannot exceed output:

$$C_i \leqslant Q_i \tag{4.4}$$

The reader not familiar with optimization is referred to Appendix 4A. The problem[3] consists of maximizing the Lagrangean function

$$\begin{aligned} L = {} & W^1(C_1^1, C_2^1, U) - \sum_i \lambda_{S_i^p}[H_i(Q_i) - S_i^p] - \sum_i \lambda_{Q_i}[Q_i - F_i(R_i)] \\ & - \sum_i \lambda_{S_i^r}[S_i^r - F_i^r(R_i^r)] - \lambda_S[\sum S_i^p - \sum S_i^r - S] - \lambda_U[U - G(S)] \\ & - \lambda_R[\sum R_i + \sum R_i^r - \bar{R}] - \lambda^2[\overline{W^2} - W^2(C_1^2, C_2^2, U)] \\ & - \sum_i \lambda_i \Big[\sum_j C_i^j - Q_i\Big] \end{aligned} \tag{4.5}$$

Note that the restraints in Eq. 4.5 are the emission function, the production function, the abatement function, the diffusion function, the damage function, and the resource restraint. These restraints define the transformation space. Also, the restraints require the constancy of utility of individual 2, the identify of total demand and the sum of individual demand, and the limitation of total demand to feasible output. The necessary conditions for an optimum of Eq. 4.5 are given in Appendix 4B. The reader is urged to derive the implications for himself in order to acquire an understanding of the mechanics of the model.

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[3] For a model with an explicit diffusion function and negative externalities, compare Siebert (1975-a).

A Shadow Price for Pollutants

From Appendix 4B we have the following results. Note that all shadow prices and all variables relate to the optimum. Normally, shadow prices are denoted by an asterisk, which we omit for simplifying purposes:

$$\lambda_U = W_U^{1'} + \lambda^2 W_U^{2'} \tag{4.6a}$$

The evaluation of one unit of environmental quality results from the aggregation of individual utilities (compare the Lindahl solution in chapter 5). Now, $W_U^{j'}(C_1^{j*}, C_2^{j*}, U^*)$ represents the marginal evaluation of the environment by individual j. If, however, we assume a social-welfare function in the maximization problem, we would have $\lambda_U, = W_U'$, that is, the shadow price of environmental quality would be determined by the "social" evaluation

$$\lambda_S = \lambda_{S_i^p} = \lambda_{S_i^r} = -G'\lambda_U \tag{4.6b}$$

The shadow price of pollutants ambient in the environment, emissions, and abated emissions is equal to the physical marginal damage of one unit of the emission multiplied by the social evaluation of the environment. Thus we already have one condition for the determination of an emission tax rate. The shadow price for emissions has to be set in such a way that it is equal to the prevented marginal damage of a unit of emission. Note that Eq. 4.6b requires the same shadow price for pollutants ambient in the environment, for emissions, and for abated emissions. This is due to the fact that we have used a simplified form of a diffusion function (Eq. 3.4)

$$\lambda_S = \frac{\lambda_R}{F_i^{r'}} \tag{4.6c}$$

The shadow price for pollutants (emissions) has to be set in such a way that it is equal to marginal abatement costs, $\lambda_R / F_i^{r'}$. The inverse function to the abatement function 3.3, $R_i^r = \phi_i(S_i^r)$, is an input requirement function. The first derivative

$$\frac{dR_i^r}{dS_i^r} = \frac{1}{dF_i^r / dS_i^r} = \frac{1}{F_i^{r'}}$$

indicates the factor input necessary to reduce one unit of pollution. If this expression is multiplied by the resource price λ_R, we obtain the marginal abatement costs.

Thus, we have two conditions for the shadow price one unit of emission. These conditions are explained in Fig. 4-1. In Fig. 4-1a, $O_1\ S_1$, denotes the quantity of emissions of sector 1, or, starting from S1, the abated emissions. The curve AS_1, denotes the marginal costs of pollution abatement in sector 1.

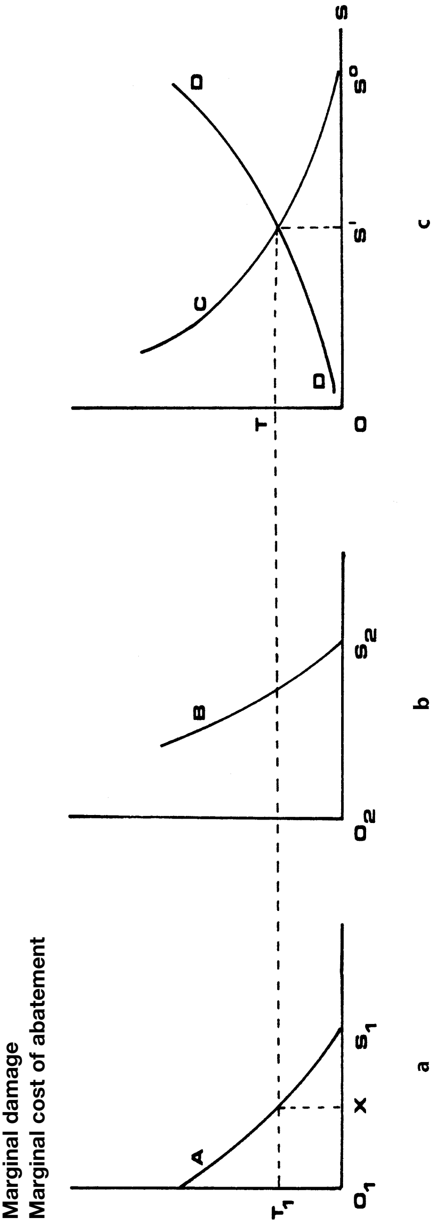

Fig. 4-1. Determination of the emission tax

With a concave abatement function, marginal costs of abatement rise progressively. Similarly, O_2S_2 in Fig. 4-1b denotes emissions of sector 2, and BS_2 indicates the marginal abatement costs in sector 2. If both curves are aggregated horizontally, CS^0 (Fig. 4-1c) represents the curve of total marginal abatement costs with OS^0 denoting the quantity of emissions in the economy in a given initial situation. The emission tax is determined by the curve CS^0. Observe that in Fig. 4-1 we have assumed that λ_R is given. Consequently, the curve CS^0, depicting marginal costs of abatement, will shift if λ_R changes. Stated differently, λ_R has been assumed to be the shadow price of the optimal solution. Similarly, the cost curve will shift if the volume of emissions changes. Therefore, Fig. 4-1 represents a partial equilibrium analysis if one assumes optimal values for a set of variables.

Curve *DD* in Fig. 4-1c specifies the evaluated marginal environmental damage of emissions (pollutants). It follows from the damage function 3.5 that marginal damage increases progressively (at a constant λ_U) with increasing emissions. When we read curve *DD* from S^0 to O, the curve represents the prevented marginal damage. Note that λ_U has been assumed to be the optimal shadow price.

The shadow price for emissions should be set in such a way that prevented marginal damage and marginal costs of abatement are equal. Now, OT is the optimal level of the shadow price for emissions, S^0S' is the quantity of the emissions to be abated, and OS' is the quantity of emissions that is tolerated. Fig. 4-1 shows the tradeoff between the improvement of the environmental quality and the costs connected with it. If one intends to improve environmental quality by abating more pollutants, then abatement costs rise, that is, resources have to be put into abatement and have to be withdrawn from the production activities. The opportunity costs of a better environment thus consist of the forgone resources used in production. Note that the interpretation of Fig. 4-1 is consistent with the analysis of chapter 3, where we have established $\partial U/\partial Q_1 < 0$. This implies that there are opportunity costs of production in terms of environmental losses or that environmental improvement implies a loss of output.

Figure 4-1c contains the basic message of economics concerning the environmental issue. If an environmental problem exists, there must be a scarcity price for using the environment. This price is determined by the marginal benefit received from environmental quality and by the costs of achieving this target. The reader will notice that other approaches such as benefit-cost analysis or the bargaining solution will lead to the same diagram.

In Eq. 4.6c, the costs of environmental policy are expressed by resources withdrawn from production. Assume that individual utility functions contain such variables as full employment, price-level stability, balance-of-payments equilibrium, or equity; then environmental policy may negatively affect these variables. If this is the case, the prevented damage of abatement is reduced, and curve *DD* in Fig. 4-1 will shift downward. Thus, if there are additional costs of environmental quality, more pollutants will be tolerated. Since we have to abate a smaller quantity of emissions, the scarcity price for pollutants will be lower.

Implications for the Shadow-Price System of the Economy

Setting a price for emissions implies that the price system of the economy will be affected. What are the implications of a scarcity price for the environment on the price vector of the economy?

$$\lambda_i = W_i^{1'} = \lambda^2 W_i^{2'} \tag{4.6d}$$

The Lagrangean multiplier λ_i denotes the shadow price of commodities from the consumers' point of view (evaluation by the consumer). Note that λ^2 is a multiplier that allows us to transform one unit of utility of individual 1 to one unit of utility of individual 2:

$$\frac{\lambda_1}{\lambda_2} = \frac{W_1^{1'}}{W_2^{1'}} = \frac{W_1^{2'}}{W_2^{2'}} \tag{4.6e}$$

The relative shadow price of the two commodities corresponds to the relation of their marginal utilities for each individual. We can also say that the relative utilities among individuals must be equal. This is a well-known result from traditional consumer theory. While the formal conditions for the household optimum are not changed when a zero shadow price is assumed for the environment, the shadow price of the pollution-intensive commodity may be affected. Its consumption may be lower

$$\lambda_{Q_i} = W_i^{1'} - \lambda_{S_i^p} H_i' = \lambda^2 W_i^{2'} - \lambda_{S_i^p} H_i' \tag{4.60f}$$

Whereas λ_i indicates the marginal evaluation of a commodity by consumers, λ_{Q_i} denotes the shadow price for producers (producers' price). The producers' price is determined by the evaluation of consumers minus the social costs of production. The social costs of production are expressed by the pollution per unit of output H_i' and the shadow price of pollutants. Equation 4.6-f indicates that the incentive for producers is corrected. The net price of the pollution-intensive commodity for producers is lowered; thus, the incentive to produce the pollution-intensive commodity is reduced:

$$\frac{\lambda_{Q_1}}{\lambda_{Q_2}} = \frac{W_1^{1'} - H_1'\lambda_S}{W_2^{1'} - H_2'\lambda_S} = \frac{\lambda^2 W_1^{2'} - H_1'\lambda_S}{\lambda^2 W_2^{2'} - H_2'\lambda_S} \tag{4.6g}$$

With a zero price charged for environmental use ($\lambda_S = 0$), relative prices are distorted for producers in the sense that not all social costs of production are attributed to individual producers. If there is a shadow price for pollutants, relative producers' price will be changed. Assume that commodity 1 is the pollution-intensive commodity, that is, $H_1' \, F_1' > H_2' \, F_2'$. Then the relative price will be changed in favor of the nonpollution-intensive commodity if an environmental policy is pursued. We can expect that the pollution-intensive sector will be restricted by the environmental policy

$$\lambda_R = \lambda_{Q_i} F'_i \tag{4.6h}$$

The resource has to be used in private production in such a way that the resource price is equal to the marginal-value product (the marginal productivity of the resource multiplied by the shadow price of the commodity[4]). When this result is written as

$$\lambda_{Q_i} = \frac{\lambda_R}{F'_i}$$

it indicates that the shadow price of a good has to be equal to its marginal production costs. The inverse to the production function is the input requirement function $R_1 = F_i^{-1}(Q_i)$. For the first derivative of this function, we have

$$\frac{dR_i}{dQ_i} = \frac{1}{F'_i}$$

If the resource input for one additional unit of output is multiplied by the resource price, we obtain the marginal production costs of the commodity.

Conditions 4.6f and 4.6h require that the producers' price of a commodity (net price) be identical to the marginal evaluation by consumers minus the social costs of production.

Optimum and Competitive Equilibrium

In the previous sections of this chapter, I analyzed the implications of a Pareto optimum when environmental problems exist. Two basic propositions of welfare economics relate optimal allocation and a competitive equilibrium to each other (Quirk and Saposnik 1968). These two propositions are as follows: A competitive equilibrium provides an optimal allocation of resources. For a given endowment of individuals, an optimal allocation can be obtained through a competitive equilibrium if an appropriate transfer is used. Do these two propositions also hold in the case of environmental disruption? In order to develop our argument, we first characterize the competitive equilibrium. In a second step, we have to relate optimal allocation to competitive equilibrium.[5]

[4] Rewrite Eq. 4.6-g as

$$\frac{\lambda_{Q_1} F'_1}{\lambda_{Q_2} F'_2} = \frac{W_1^{i\prime} F'_1 + H'_1 F'_1 \lambda_S}{W_2^{i\prime} F'_2 + H'_2 F'_2 \lambda_S}$$

[5] On a general equilibrium with explicit consideration of the environment also compare Dudenhöffer (1983), Maler (1985) and Pethig (1979).

Competitive Equilibrium

A competitive equilibrium is defined as an allocation A and a price vector **P** so that for $[A, P]$

1. All markets are cleared.
2. Each consumer maximizes his utility subject to the budget restraint.
3. Each producer maximizes his profit subject to the production function.

Consumers

It is assumed that each consumer maximizes his utility for given prices ($\tilde{p}_i$, $\tilde{r}$), where $\tilde{p}_i$ are market prices for commodities and $\tilde{r}$ is the resource price. The government levies an emission tax $\tilde{z}$. Government receipts from emission taxes are transferred to the households. Profits of the production sector are also transferred to the households according to a given distribution parameter (profit shares). With given factor prices and a given distribution parameter, the income Y^j is given for the individual household. Household j maximizes the Lagrangean expression

$$L = W^j(C_1^j, C_2^j, U) - \lambda_Y^j(\tilde{p}_1 C_1^j + \tilde{p}_2 C_2^j - Y^j)$$

Environmental quality is given for the individual household. The necessary conditions for the household optimum are

$$W_i^{j\prime} - \lambda_Y^j \tilde{p}_i \leqslant 0$$

and (4.7)

$$\sum_i \tilde{p}_i C_i^j - Y^j \leqslant 0$$

Note that λ_Y^j is the shadow price of a unit of income (or money) of individual j. Since marginal utilities are measured in utils and prices in money, λ_Y is a conversion factor which transforms units of money into utils.

Producers

It is assumed that each producer maximizes his profit for given prices $\tilde{p}_i$, $\tilde{r}$, $\tilde{z}$

$$\Pi_i = \tilde{p}_i Q_i - \tilde{r}(R_i + R_i^r) - \tilde{z} S_i$$

subject to

$$\begin{aligned} &Q_i - F_i(R_i) \leqslant 0 \qquad && S_i^r - F_i^r(R_i^r) \leqslant 0 \\ &H_i(Q_i) - S_i^p \leqslant 0 \qquad && -S_i + S_i^p - S_i^r = 0 \end{aligned} \tag{4.8}$$

From Appendix 4C we have

$$\tilde{r} \geqslant (\tilde{p}_1 - \tilde{z}H'_1)F'_1(R_1) = \tilde{p}_1^* F'_1 \tag{4.9a}$$

$$\tilde{r} \geqslant (\tilde{p}_2 - \tilde{z}H'_2)F'_2(R_2) = \tilde{p}_2^* F'_2$$

$$\tilde{r} \geqslant \tilde{z}F_i^{r'}(R_i^r) \tag{4.9b}$$

Assume $R_i > 0$. Then Eqs. 4.9a and 4.9b specify that the producer will use resources in production up to a point where the marginal-value product of a resource is equal to the price of the resource. Note that the marginal-value product in this case is defined with respect to the producers' price or net price $\tilde{p}_i^*$, that is, market price $\tilde{p}_i$ minus emission tax $\tilde{z}$ per unit of output $\tilde{z}H'_i$. Condition 4.9a indicates that an emission tax sets a new price signal for production. *Ceteris paribus*, the net price of a pollution-intensive commodity will be lower because of a higher emission tax per unit of output. Thus, the incentive to produce the pollution-intensive commodity will be reduced.

Equation 4.9b requires that, for $R_i^r > 0$, the marginal-value product of a resource in abatement $\tilde{z}F_r^{i'}$ be equal to the resource price. Assume that $\tilde{r}$ and $\tilde{z}$ are given; then we have an incentive to use resources for abatement. If, *ceteris paribus*, $\tilde{z}$ is increased, $F_i^{r'}$ must fall and R_i^r must rise.

In Table 4-1 the conditions for Pareto optimality, for a utility maximum of the household, and for a profit maximum of the firm are reproduced. Intuitively, the reader can see that the conditions for the Pareto optimum and perfect competition are very similar.

Table 4-1. Pareto optimum and competitive equilibrium

Pareto Optimum		Competitive Equilibrium[a]	
$W_i^{1'} - \lambda_i^1 \leqslant 0$	(1)	$W_i^{j'} - \lambda_Y^j \tilde{p}_i \leqslant 0$	(1)
$\lambda^2 W_i^{2'} - \lambda_i^2 \leqslant 0$	(1a)		
$(\lambda_i - \lambda_{S_i^p} H'_i)F'_i - \lambda_R \leqslant 0$	(2)	$(\tilde{p}_i - \tilde{z}H'_i)F'_i - \tilde{r} \leqslant 0$	(2)
$\lambda_{S_i^r} F_i^{r'} - \lambda_R \leqslant 0$	(3)	$\tilde{z}F_i^{r'} - \tilde{r} \leqslant 0$	(3)
$\sum_j C_i^j - Q_i = 0$	(4)	$\sum_j C_i^j - Q_i = 0$	(4)
$\bar{R} - \sum_i R_i - \sum_i R_i^r = 0$	(5)	$\bar{R} - \sum_i R_i - \sum_i R_i^r = 0$	(5)

[a] It is assumed that $S_i > 0$ so that from Eq. 4C.4 $\tilde{z} = \lambda_{S_i}$. Then since $\lambda_{S_i} \leqslant \lambda_{S_i^r}$, the term $-r + \lambda_{S_i^r} F_i^{r'} \leqslant 0$ can be written as $-r + \tilde{z}F_i^{r'} \leqslant 0$.

Optimal Environmental Allocation in a Competitive Economy

We can now establish the two propositions of welfare economics for an economy with environmental disruption.

Proposition 1. Let [*A*, *P*] denote a competitive equilibrium with allocation *A* and price vector **P** = ($\tilde{p}_1$, $\tilde{p}_2$, $\tilde{r}$, $\tilde{z}$). Let prices be

$$\tilde{p}_i = \frac{\lambda_i}{\lambda_Y^1} = \frac{\lambda_i}{\lambda^2 \lambda_Y^2} \quad \text{with } \lambda_Y^1 = \lambda^2 \lambda_Y^2$$

$$\tilde{r} = \frac{\lambda_R}{\lambda_Y^1}$$

$$\tilde{z} = \frac{\lambda_{S_i^p}}{\lambda_Y^1} = \frac{-(W_U^{1'} + \lambda^2 W_U^{2'})G'}{\lambda_Y^1}$$

Then *A* is Pareto-optimal.

Proof. Now, *A* is a competitive equilibrium. Consequently, the price vector **P** satisfies the conditions in column 2 of Table 4-1. The market equilibrium conditions 4 and 5 are given. They are identical to the restraints 4 and 5 of the optimum. By setting $\tilde{z}$ equal to $-(W_u^{1'} + \lambda^2\ W_u^{2'})\ G'/\lambda_Y^1$, and with the other prices as indicated above, and then substituting these prices into the conditions of a competitive equilibrium (second column), we obtain the conditions of the optimum. Therefore, the allocation *A* is optimal.

Proposition 2. Let *A* * be a Pareto-optimal allocation so that the conditions of column 1 in Table 4-1 hold. Then a price vector **P*** including emission taxes exists such that [*A**, *P* *] constitutes a competitive equilibrium.

Proof. Let prices be defined as in proposition 1. Then, after substituting these definitions into column 1, we obtain the conditions of column 2. These conditions together with the constraints are identical to those of a competitive equilibrium. Consequently, *A** is a competitive equilibrium.

Requirements for an Emission-Tax Solution

In this chapter we show that a maximization model yields shadow prices for environmental use. If we view the implications of an optimization model as a guideline for economic policy, then our model indicates the informational requirements for the setting of an emission tax. These requirements are:

1. The policymaker needs information on the quantity of emissions. The emissions must be measurable with reasonable costs.

2. The policymaker needs information on the level of abatement costs for alternative states of the environment.
3. The policymaker must be able to determine (and to evaluate) prevented damage.
4. The diffusion function between emissions and pollutants ambient in the environment must be known.

In chapters 7 and 8 we analyze some of the problems that arise when an emission tax is implemented.

Appendix 4 A: Nonlinear Optimization

Let $f(x) = f(x_1, x_2, \ldots, x_n)$ denote a differentiable concave function that has to be maximized. Let the vector

$$g(x) = \begin{bmatrix} g_1(x) \\ g_2(x) \\ \vdots \\ g_m(x) \end{bmatrix} \geqslant 0$$

be a differentiable and concave function that has to be regarded as a restriction. Then the optimizing problem is to find a vector x^* which maximizes $f(x)$ under the constraints $g(x) \geq 0$ and $x \geq 0$. The procedure is to form the Lagrangean function

$$L(x, \lambda) = f(x) + \lambda'_g(x)$$

where

$$\lambda = \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_m \end{bmatrix} \geqslant 0$$

is the Lagrangean multiplier λ and where λ' denotes the row vector of λ. Here x^* is the optimal solution of the maximization problem if a vector $\lambda^* \geq 0$ exists and if

$$L_x(x^*, \lambda^*) \leqslant 0 \qquad x^* L_x(x^*, \lambda^*) = 0 \qquad x^* \geqslant 0$$

$$L_\lambda(x^*, \lambda^*) \geqslant 0 \qquad \lambda^* L_\lambda(x^*, \lambda^*) = 0 \qquad \lambda^* \geqslant 0$$

is fulfilled for L (x, λ). If the qualification of the Slater-secondary condition is fulfilled, the aforementioned conditions are necessary and sufficient for a global maximum.

Observe that if $g(x)$ is convex, then the constraint is expressed as $g(x) \leq 0$.[1]

Appendix 4B: Implications of the Allocation Problem

The Kuhn-Tucker conditions for Eq. 4.5 are

$$\frac{\partial L}{\partial C_i^1} = W_i^{1\prime} - \lambda_i \leqslant 0 \qquad C_i^1 \geqslant 0 \qquad C_i^1 \frac{\partial L}{\partial C_i^1} = 0 \tag{4 B.1}$$

$$\frac{\partial L}{\partial U} = W_U^{1\prime} - \lambda_U + \lambda^2 W_U^{2\prime} \leqslant 0 \qquad U \geqslant 0 \qquad U \frac{\partial L}{\partial U} = 0 \tag{4 B.2}$$

$$\frac{\partial L}{\partial R_i} = \lambda_{Q_i} F_i' - \lambda_R \leqslant 0 \qquad R_i \geqslant 0 \qquad R_i \frac{\partial L}{\partial R_i} = 0 \tag{4 B.3}$$

$$\frac{\partial L}{\partial R_i^r} = \lambda_{S_i^r} F_i^{r\prime} - \lambda_R \leqslant 0 \qquad R_i^r \geqslant 0 \qquad R_i^r \frac{\partial L}{\partial R_i^r} = 0 \tag{4 B.4}$$

$$\frac{\partial L}{\partial S_i^p} = \lambda_{S_i^p} - \lambda_S \leqslant 0 \qquad S_i^p \geqslant 0 \qquad S_i^p \frac{\partial L}{\partial S_i^p} = 0 \tag{4 B.5}$$

$$\frac{\partial L}{\partial S_i^r} = -\lambda_{S_i^r} + \lambda_S \leqslant 0 \qquad S_i^r \geqslant 0 \qquad S_i^r \frac{\partial L}{\partial S_i^r} = 0 \tag{4 B.6}$$

$$\frac{\partial L}{\partial S} = \lambda_S + \lambda_U G' \leqslant 0 \qquad S \geqslant 0 \qquad S \frac{\partial L}{\partial S} = 0 \tag{4 B.7}$$

$$\frac{\partial L}{\partial C_i^2} = \lambda^2 W_i^{2\prime} - \lambda_i \leqslant 0 \qquad C_i^2 \geqslant 0 \qquad C_i \frac{\partial L}{\partial C_i^2} = 0 \tag{4 B.8}$$

$$\frac{\partial L}{\partial Q_i} = -\lambda_{S_i^p} H_i' - \lambda_{Q_i} + \lambda_i \leqslant 0 \qquad Q_i \geqslant 0 \qquad Q_i \frac{\partial L}{\partial Q_i} = 0 \tag{4 B.9}$$

$$\frac{\partial L}{\partial \lambda} \geqslant 0 \qquad \lambda \geqslant 0 \qquad \lambda \frac{\partial L}{\partial \lambda} = 0 \tag{4 B.10}$$

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[1] On the technique of nonlinear optimization, compare A.-C. Chiang, *Fundamental Methods of Mathematical Economics* (New York: McGraw-Hill, 3rd edition, 1984); A. Takayama, *Mathematical Economics* (New York: The Dryden Press, 2nd edition, 1985), chap. 1.

where λ denotes the vector of Lagrangean multipliers. Note that Eq. 3.4 requires the strict equality. In this case, we can write Eq. 3.4 as two different types of inequalities (greater than or equal to zero and less than or equal to zero), thereby implying equality.

The Lagrangean multipliers are interpreted as follows: First, consider a constraint which restricts the variable by an absolute value such as $\bar{R}$. Then a parametric change in $\bar{R}$, that is, $dL/d\bar{R} = \lambda_R$, indicates how the value of the Lagrangean function is changed if $\bar{R}$ is marginally varied. For instance, λ_R denotes the value of one unit of the resource for the goal function. So λ_R can be interpreted as the shadow price of the resource. Second, now consider the case in which the variable is not restricted by an absolute value but, rather, by a function, as in $Q \leq F(R)$. Then we can find an interpretation of the Lagrangean multiplier by introducing a disposal activity (slack variable). Such a fictive activity disposes of one unit of a variable. Define D as quantities of output removed from the system, so that the constraint can be written as $Q+D = F(R)$. Then the constraint is transformed to $-\lambda_Q[Q+D-F(R)]$. The expression $\partial L/\partial D = -\lambda_Q$ indicates how the value of the goal function is changed when one unit of output is eliminated from the system, and λ_Q is the shadow price of output.

All other Lagrangean multipliers can be interpreted similarly. In Eq. 4.5 we have already characterized the Lagrangean multiplier by the appropriate indices.

The interpretation of our optimization problem is made easier by some reasonable assumptions. Since $R_i > 0$ or $R_3 > 0$, $\lambda_R > 0$. Also assume that both sectors produce, so that R_i, Q_i, $S_i^p > 0$. Let some environmental quality exist so that $U > 0$. Let both individuals demand positive quantities of the two commodities. Finally, if $\lambda_{S_i^r} > 0$ (this is an implicit price for pollutants), then $R_i^r > 0$. Under these assumptions, the conditions in 4B.1 to 4B.10 are all equalities.

Appendix 4C: Implications of the Profit Maximum

The Lagrangean function of the problem in 4.8 is

$$L_i = \tilde{p}_i Q_i - \tilde{r}(R_i + R_i^r) - \tilde{z} S_i - \lambda_{S_i^p}[H_i(Q_i) - S_i^p] - \lambda_{Q_i}[Q_i - F_i(R_i)] \\ - \lambda_{S_i^r}[S_i^r - F_i^r(R_i^r)] - \lambda_{S_i}[S_i^p - S_i^r - S_i]$$

The necessary conditions for the maximum of the problem in 4.8 are

$$\frac{\partial L}{\partial Q_i} = \tilde{p}_i - \lambda_{Q_i} - \lambda_{S_i^p} H_i' \leqslant 0 \qquad Q_i \geqslant 0 \qquad Q_i \frac{\partial L}{\partial Q_i} = 0 \tag{4 C.1}$$

$$\frac{\partial L}{\partial R_i} = -\tilde{r} + \lambda_{Q_i} F_i' \leqslant 0 \qquad R_i \geqslant 0 \qquad R_i \frac{\partial L}{\partial R_i} = 0 \tag{4 C.2}$$

$$\frac{\partial L}{\partial R_i^r} = -\tilde{r} + \lambda_{S_i^r} F_i^{r'} \leqslant 0 \qquad R_i^r \geqslant 0 \qquad R_i^r \frac{\partial L}{\partial R_i^r} = 0 \tag{4 C.3}$$

$$\frac{\partial L}{\partial S_i} = -\tilde{z} + \lambda_{S_i} \leqslant 0 \qquad S_i \geqslant 0 \qquad S_i \frac{\partial L}{\partial S_i} = 0 \tag{4 C.4}$$

$$\frac{\partial L}{\partial S_i^r} = -\lambda_{S_i^r} + \lambda_{S_i} \leqslant 0 \qquad S_i^r \geqslant 0 \qquad S_i^r \frac{\partial L}{\partial S_i^r} = 0 \tag{4 C.5}$$

$$\frac{\partial L}{\partial S_i^p} = \lambda_{S_i^p} - \lambda_{S_i} \leqslant 0 \qquad S_i^p \geqslant 0 \qquad S_i^p \frac{\partial L}{\partial S_i^p} = 0 \tag{4 C.6}$$

$$\frac{\partial L}{\partial \lambda} \geqslant 0 \qquad \lambda \geqslant 0 \qquad \lambda \frac{\partial L}{\partial \lambda} = 0 \tag{4 C.7}$$

5 Environmental Quality as a Public Good

In this chapter we analyze the public-goods approach to the environmental problem. Environmental quality is considered to be a public good that must be consumed in equal amounts by all. This approach starts from the premise that private property rights cannot be defined for environmental quality (or if technically feasible, that private property rights should not be defined). Then the market cannot allocate the environment, and government intervention becomes necessary. How does the government determine the desired environmental quality? One approach is to assume a social-welfare function which allows us to specify the benefits and costs of environmental quality. In a similar way, benefit-cost analysis implicitly presupposes a social-welfare function as a guideline for evaluation. Another approach is to base the evaluation of environmental quality on individual preferences. A Pareto-optimal allocation requires individualized prices of environmental quality to be assessed according to the individual's willingness to pay. If individuals are not inclined to reveal their true willingness to pay, we have to look into institutional arrangements that may reveal and aggregate individual preferences.

Characteristics of a Public Good

It is useful to distinguish between the polar cases of private and public goods. A private good can be attributed to a specific individual. Individuals compete against each other in using the good, and potential users can be excluded. There is rivalry in use and private property rights exist. The concept of competing uses can be expressed as

$$C^1 + C^2 + \cdots + C^n = Q \tag{5.1}$$

where C denotes quantities of a good and the superscripts indicate individuals.

A pure public good is consumed in equal amounts by all (Samuelson 1954); the pure public good cannot be parceled out to individuals. The use by one individual does not subtract from any other individual's use. There is no rivalry in use. Individuals cannot be excluded from using the public good; that is, in contrast to a private good, property rights cannot be attributed to individuals. Consequently, a public good U is characterized by

$$U^1 = U^2 = \cdots = U^n = U \tag{5.2}$$

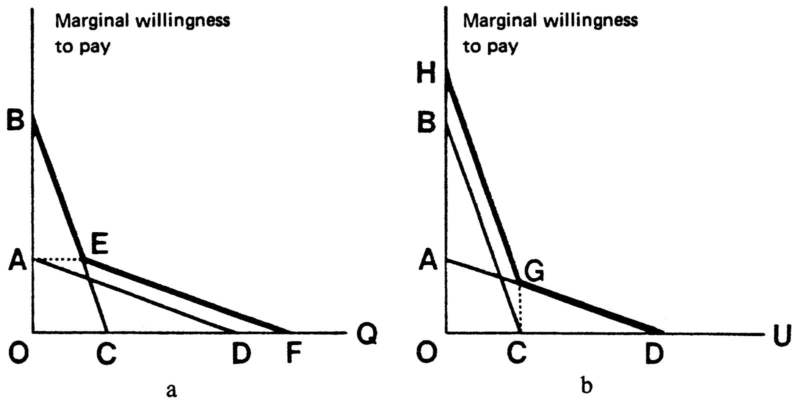

Fig. 5-1. Aggregation of willingness to pay

The difference between the polar cases of private and public goods is illustrated in Fig. 5-1. Total demand for a private good of an economy is summed horizontally; that is, we add quantities. In Fig. 5-1a curves BC and AD indicate the marginal willingness to pay, that is to give up income, of two different individuals. Marginal willingness to pay decreases with the quantity according to the usual property of demand functions. Curve BEF denotes the marginal willingness of both individuals or the willingness to pay signaled in the market. In the case of a public good, quantities cannot be added; rather, we add vertically, that is, we sum the individual evaluations. Again curves BC and AD denote the willingness to pay of both individuals. Since the public good must be used in equal amounts by all, the willingness to pay of both individuals, e.g., curve HGD, is found by aggregating vertically.

A public good is characterized by the technical property that the commodity is to be used in equal amounts by all. Actually, this property depends on the given exclusion technology. For instance, the lighthouse – the prototype of a public good – may well be considered to be a private good if a device is necessary to receive signals from the lighthouse. Indeed, we may conceive of exclusion technologies in many cases so that property rights can be attributed, and public goods are changed into private ones. However, even if an exclusion technology exists, we may judge the good so meritorious that the exclusion technology should not be applied. In this case we speak of a merit good. Also, the exclusion technology may not be acceptable under normative constraints.

The merit good is on the border line between a private and a pure public good. Exclusion is technically feasible, for instance by excluding someone from a school system, and there is some rivalry in use, for instance by an additional student reducing the quality of a school. Rivalry in use may give rise to congestion problems. Thus, between the polar cases of pure private and pure public goods we have many intermediate forms. Note that on this border line, the two characteristics used in Table 5-1 may not be independent of each other;

Table 5-1. Classification of Goods

Characteristics of good / Institutional arrangement	Exclusive property rights	Nonexclusive property rights
Rivalry in use	Private good	Common-property resource
		Merit good
Nonrivalry in use		Pure public good

the institutional setting of property rights also defines the characteristics of goods.

In yet another intermediate form, a public good may be limited by membership (theory of clubs), by space (local public goods), or by time. In this case, there is no rivalry for those who can use the good, but some form of exclusion exists.

In Table 5-1 the two criteria of the institutional arrangement of exclusive property rights and the characteristics of the good with respect to rivalry or nonrivalry are used to classify goods.

The terms *public good* and *common-property resource* are often used synonymously. However, they should be clearly distinguished. A common-property resource is a good for which exclusive property rights are not defined and where rivalry in use prevails. The nonexistence of exclusive property rights means that access to the good is not limited or not severely limited. Consequently, the users compete with each other eventually affecting the quantity available or the quality (congestion). In contrast to merit goods where access is not limited for normative reasons and where a deliberate decision is taken not to limit access, in the case of common-property resources, property rights are not clearly defined because of historical conditions, although exclusion mechanisms are possible. It is mainly for historical reasons that commonproperty resources are used as free goods. In the past, many goods were free goods and common-property resources simultaneously; today, because of increased scarcity and the more comprehensive definition of property rights, they have become private goods. For instance, fish as a protein source have been used as a common-property resource in the world's oceans because no property rights were assigned. Today, some forms of property rights such as the 200 mile zone and limitations-on economic harvesting begin to emerge.

How is the environment related to the public-goods concept? In chapter 2 we discuss the functions of the environment for the economic system; not all these functions define characteristics of a public good. For instance, in its role as a receptacle of waste, the environment can be interpreted as a commonproperty resource, but not as a public good. Similarly, the provision of natural resources such as water does not fall under the heading of a public good. In ancient times water may have been used as a free good because of its bounty. This abundance rendered competing uses and rivalry and hence the installation of a property rights system meaningless whatever service water did provide. Water was used as a common-property resource. But eventually, as water became scarce, a system of modified property rights was developed for the different services water did provide. Property rights for other national resources such as land, oil, and wood are well established. It is only with respect to the role of the environment as a supplier of public-consumption goods (such as beautiful landscapes, air to breathe, or other life-supporting systems) that the public-goods approach becomes relevant.

For the discussion of this topic, the following aspects should be clearly distinguished:

1. If the environment is used as a common-property resource (receptacle of waste, provider of natural resources such as water and fish) and if this resource becomes scarce, the characteristic of the common-property resource has to be changed by introducing scarcity prices or other allocation mechanisms.
2. Some functions of the environment (provision of life-supporting systems, amenities, and so on) constitute a public good. In the following analysis, we summarize these functions through use of the term *environmental quality*. We know that the definition of a public good depends on existing exclusion technologies and value judgments. Consequently, the problem arises as to whether, for specific uses of the environment, the public good can be changed into a private one. In this chapter, we analyze the public-goods problem within the context of the environmental issue. In chapter 6, the attribution of property rights is studied.

Allocation of Public Goods

The existence of a public good implies that an individual can take the position of a free rider. Once the public good exists or once it is produced, an individual may use the public good, but he may not be willing to contribute to its costs of production. If the individual is asked to indicate his willingness to pay for the public good, he may give false answers. For instance, if he expects that his answer will serve to calculate his share of costs for the public good, he may understate his preference for the public good (including the extreme case of a zero willingness to pay), expecting that those with a higher willingness to pay will guarantee that the good will be provided. If the individual does not anticipate having to contribute to the costs of production, he may overstate his preference for the public good.

In the case of private goods, the individual cannot take the position of a free rider. If he wants a specific good, he has to give up income for it. His willingness to pay is indicated by the market price. Since his income could be used for other goods, the individual's willingness to pay also indicates his opportunity costs. Thus, the market process reveals the willingness to pay. This demand-revealing process does not operate in the case of public goods since they cannot be attributed to individuals.

The consequence is that public goods should not be allocated through the market mechanism, in order to prevent a misallocation of resources. Public goods require government activity. Actually, there is a wide range of potential government activities. If the public good "environmental quality" cannot be allocated through the market mechanism, three problems arise as to what quantity of the public good "environmental quality" should be provided, by which procedures this target is determined, and by which mechanism the fulfillment of the target can best be reached.

With respect to the determination of the target variable, we can assume that the government will determine the desired environmental quality. Either the government knows what the people want, or it does not take individual preferences into consideration. Western constitutional democracy, having developed over centuries, stresses that individual value judgments should ultimately determine the targets of government activity. But how can individual preferences be revealed if the individual can take the position of the free rider? With this background, the following approaches to the problem of environmental allocation can be distinguished:

1. A social-welfare function is given to the policymakers, including environmental quality as an independent variable. Environmental quality is determined by maximizing this function.
2. Through a more pragmatic approach, the government studies the benefits and costs of environmental policy and uses this information to determine the desired environmental quality.
3. The government tries to base its target values on individual preferences and assigns individualized prices for environmental quality (Lindahl solution).
4. Since the Lindahl solution does not guarantee that individual preferences are truly revealed, other mechanisms of social choice are sought.

Social-Welfare Function

Assume a given social-welfare function of the policymaker in which private goods C_i and environmental quality U are independent variables. Also, other policy variables such as the employment level E, price-level stability P, and the balance-of-payments situation B are included in the welfare function

$$W = W(C_1, C_2, U, E, P, B) \tag{5.3}$$

Then the allocation problem consists of maximizing Eq. 5.3 subject to the transformation space, that is, the constraints discussed in chapters 3 and 4.

An important implication of this approach is similar to that found in the optimization model (Eq. 4.6 a).

$$\lambda_S = \frac{\lambda_R}{F_i^{r'}} = -G'\lambda_U \tag{5.4}$$

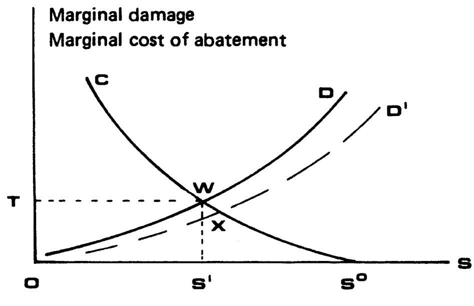

Fig. 5-2. Optimal environmental quality

The shadow price for pollutants has to be set in such a way that the marginal costs of abatement are equal to the prevented marginal environmental damage. Here G' denotes marginal damage in physical terms (per unit of pollutant), and λ_U indicates the evaluation of one unit of the environment by the policymaker. The minus sign on the right-hand side of Eq. 5.4 can be interpreted as prevented damage.

The implication of this approach is explained in Fig. 5-2 where OS^0 denotes emissions and, if viewed from S^0 toward O, emissions abated. Curve S^0C presents marginal abatement costs; these costs can be interpreted as opportunity costs, that is, costs of a forgone opportunity. In terms of the transformation space, these opportunity costs mean less commodities. Curve OD represents the marginal damage of pollutants. Read from S^0, curve OD can be interpreted as prevented damage. Also OS' is the optimal level of pollution, that is, the target value, and S^0S' represents the quantity of pollutants to be abated. And OT is the shadow price per unit of emission. Note that Fig. 5-2 is interpreted in the same way as Fig. 4-1 c.

In addition to forgone income (bypassed production opportunities), environmental policy may negatively affect other target variables of economic policy such as full employment or price-level stability. If this is the case, curve OD shifts downward to OD', and fewer pollutants have to be abated (point X). The losses in terms of economic-policy variables reduce the desired level of environmental quality.

The problem of this approach lies in the assumption that a social-welfare function – the economist's most favorable fiction – exists. For instance, we may assume that there is a superman or a dictator who knows what is good for the people. If, however, the social-welfare function is to be aggregated from individual preferences, we may encounter problems. Assume that we postulate the following: preference aggregation is feasible for all possible combinations of complete and individual preference orderings (unrestricted domain); it must change if one individual changes his ranking, given the indifference of all other individuals (Pareto optimality); it should not be dictatorial (nondictatorship condition); it must be independent of irrelevant alternatives (independence of the irrelevant alternatives); it must not be imposed by someone (nonimposition condition) (Arrow 1951; Quirk and Saposnik 1968). It can be shown that no social ranking exists that satisfies these five conditions [Arrow's impossibility theorem].

Benefit-Cost Analysis

The pragmatic analogue to the approach of the social-welfare function in environmental policy is benefit-cost analysis. This approach was first used in public-investment projects such as irrigation systems and reservoir dams. The benefits and costs of alternative projects were analyzed, and for given investment funds, the project providing the maximum net benefit was given priority. Benefit-cost analysis has also been applied in cases where a target level had to be determined. Thus, benefit-cost analysis can be used to determine the benefits and costs of environmental quality. Assume that gross benefits B and costs C are continuous functions of environmental quality U, and let $N(U)$ denote net benefits. Then the problem of determining the optimal environmental quality is given by maximizing

$$N(U) = B(U) - C(U) \tag{5.5}$$

The maximum net benefit is reached when

$$\frac{dB}{dU} = \frac{dC}{dU} \tag{5.6}$$

Equation 5.6 states that the marginal benefits of environmental quality are equal to its marginal costs. This condition is identical to the condition stated in Eqs. 4.6b and c. Marginal benefits can be interpreted as prevented damages, and costs are identical to abatement costs and forgone target values. Equation 5.6 can be explained by Fig. 5-2 where CS^0 indicates abatement costs and OD signifies prevented damage. Benefit-cost analysis obtains the same result as the maximization of a social-welfare function. This is not surprising since the benefit-cost approach presupposes that benefits can be determined, that is, that the evaluation of damages is possible. Implicitly, a welfare function is assumed to exist. Thus, the benefit-cost approach can be regarded as a rudimentary optimality model determining optimal environmental quality.

In the following analysis, we look into the problem of whether, in a pragmatic approach, benefits and costs of environmental policy can be determined. Even in this practical approach we must confront some of the theoretical problems already discussed, such as the free-rider dilemma. Since it is easier to specify the costs of environmental policy, we begin with this factor.

Costs of Environmental Quality

There are two types of costs of environmental quality: resource costs and target losses for economic policy.[1]

Abatement Costs

Costs of pollution abatement arise because improving environmental quality requires resources. A firm being forced to reduce its emissions by a given percentage has to use resources to abate pollutants. Or assume that the firm has to pay a tax per unit of emissions. Then the firm will abate pollutants as long as abatement is more profitable than paying taxes. Many older studies indicate that abatement costs of sectors of the economy rise progressively.[2] This, for instance, is the result of a series of OECD studies of abatement costs for specific sectors in industrial countries in the 1970s (OECD 1972a, 1977a,b). Figure 5-3 a shows such a cost curve for some sectors of the West German economy.[3] More recent studies indicate similar cost functions (Roberto 2000; Harrington 2001; World Bank 2004); these functions shift downward with improved technology and lower fuel prices (Carlson et al. 2000). Marginal cost functions have been integrated into applied general equilibrium models (Böhringer and Löschel 2003). Abatement costs can be explained by engineering production and abatement functions.

The empirical estimation of such abatement cost functions runs into quite a few difficulties. Take the case of the abatement costs for airborne cadmium emissions (Klepper and Michaelis 1992). Abatement technologies reduce not only cadmium, but a set of different substances such as dust, heavy metals, and organic waste. Therefore, it may not be justified to attribute total costs to cadmium alone. Newer technologies such as fabric filters not only have a higher removal capacity, but will also hold back other emissions such as smaller dust particles. The sketchy data available suggest that older technologies, such as scrubbers, tend to have relatively high operating costs, whereas more recent arrester technologies, such as electrostatic precipitators (ESP) and fabric filters, tend to have lower operating costs but higher investment costs. Investment cost functions exhibit falling average investment costs and seem to follow a cost function $C = \alpha v^{\beta}$ where $\beta < 1$ (for instance 0.9 for electrostatic precipitator). Figure 5-3 b shows investment costs of advanced dust arresters for coal combustion facilities.

Sectoral or macroeconomic abatement cost functions can be explained in a bottom-up process through engineering abatement functions. In a macroeconomic context, the abatement functions influence the transformation space (Fig. 3-3). Assuming environmental quality is to be improved, i.e., we move

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[1] This distinction is not clear-cut since resource costs can also be interpreted as a target loss, namely, as a decline of national income.

[2] Compare, for instance, Kneese and Bower (1979, chap. 4); OECD (1977a,b) with respect to the aluminum, fertilizer, metal industry.

[3] On data compare Der Rat von Sachverständigen für Umweltfragen (1978, p. 115).

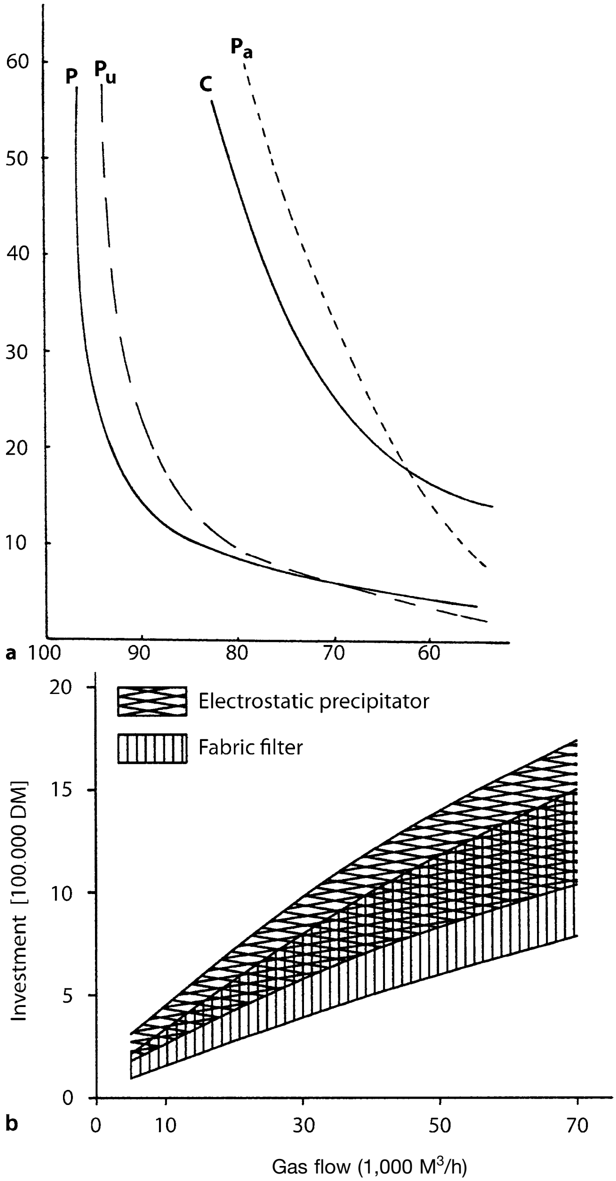

Fig. 5-3a,b. The vertical measures marginal costs in German marks per unit of pollution abatement with respect to water quality. The horizontal axis indicates pollutants abated in percent. Here *C* is chemical industry, *P* is paper, P_a is public abatement, and P_u is pulp. **a** Abatement costs in selected sectors; **b** Investment costs of advanced arresters for coal combustion facilities[4]

[4] Klepper and Michaelis (1992).

up the transformation space, then the quantity of commodities is reduced. At a given production technology, there is a trade-off between environmental quality and the availability of other goods. Resource costs are opportunity costs since resources used for abatement are lost for production purposes. In Fig. 3-3, opportunity costs are indicated by the slope $dQ1/dU$ of the transformation space for a given quantity 2. This marginal rate of transformation tells us what quantity of commodity 1 we have to give up for one additional unit of environmental quality.

Recently, cost estimates have been undertaken with respect to reducing carbon dioxide in order to prevent global warming. Such cost estimates are also relevant in predicting how emission trading will work and which prices to expect for emission rights. In these approaches, applied general equilibrium models are used (see Appendix 2B). For instance, the GREEN Model was used to calculate a carbon tax in constant 1985 US $ which is necessary to satisfy three alternative carbon reduction scenarios (reduction of the emission growth rate of a base line case by 1, 2, or 3 percentage points). Many other approaches have been published meanwhile (Babiker et al. 2003; Bernard and Vielle 2003; Böhringer and Löschel 2003; Dellink 2005; Hyman et al. 2002; Klepper and Peterson 2004b, 2006; Lucas 2002). How high the emission tax must be in order to bring about the necessary reduction, depends on a number of factors. Countries with high energy prices have already used energy-saving devices; their marginal costs of emission reduction are high in comparison to countries which have low energy prices. Thus, Japan can be expected to have higher reduction costs than the US. The substitution potential may be quite different among countries. Countries which rely on carbon-intensive energy such as coal can substitute away from coal and can do this at relatively low costs. Countries, however, which do not rely so much on carbon-intensive energies do not have such a large substitution potential. A backstop technology may only become available at very high marginal costs of reduction. Thus, backstop technologies may only become competitive in those regions of the world where the carbon tax is high.

Figure 5-3 c compares the abatement cost per ton of CO_2 for Japan and the US (Criqui et al. 2003). Without emission trading in the context of the Kyoto Protocol, a survey of 15 different modeling approaches estimates the marginal cost per tonne of CO_2 abated in a range of 20 to 665 US-dollars; the costs for the US are estimated at 168 US-dollars, for OECD-Europe at 204, and Japan at 304 (Perman et al. 2003, Table 10.9).

Target Losses as Costs

The second category of costs is target losses. To what extent will the improvement of environmental quality affect employment, price-level stability, economic growth, and the balance-of-payments equilibrium? Cost estimates of reaching environmental quality targets indicate that as a rule, resource costs for the economy as a whole are in the range of 1–3 percent of gross national product.

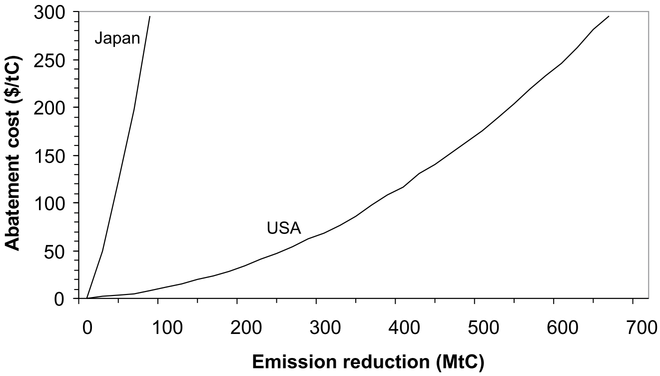

Fig. 5-3c. Marginal abatement costs in Japan and the US[5]

This figure is also the long-run estimate for keeping CO_2 emissions at their 1990 level (World Resources Institute and World Bank 1996). In the context of the Kyoto Protocol without emission trading, a survey of 15 different modeling approaches estimates the reduction in GDP for the 2010 emission targets for the US at 1.06 percent, for OECD-Europe at 0.81, and Japan at 0.72 percent (Perman et al. 2003, Table 10.9). Applied general equilibrium models are used to analyze these effects. Such models allow to take into account not only direct effects, but all the repercussions in the system – the so-called ripple effects. Jorgenson and Wilcoxen (1990a) found in an applied general equilibrium model that the long-term real level of GNP in the US is reduced by 2.5 percent due to environmental regulation. Another study (Hazilla and Kopp 1990) comes to the conclusion that environmental regulation reduces labor productivity, and therefore leads to a reduced supply of labor. Other topics are the impact on competitiveness (Jorgenson and Wilcoxen 1990a) and employment effects of environmental policy. A more recent study (Intergovernmental Panel on Climate Change 2001a–d) estimates GDP losses for the US to between 0.45 and 1.96 percent of GDP without emission trading (versus to between 0.31 and 1.03 percent with trading). For the EU the estimate ranges to between 0.31 and 2.08 percent without trading; for Japan the range is between 0.25 and 1.88, again without emission trading. The Stern report (Stern 2007) estimates the annual cost of greenhouse gas reduction by 25 percent of the current level until 2050 to between minus 1 and plus 3.5 percent of GDP. The wide range is due to the uncertainty relating to innovation in energy efficiency and abatement technology.

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[5] Source: Criqui et al. (2003).

Impact on Employment

Environmental policy will create new jobs in abatement activities as in the eco-industry where new abatement capital is produced (Lindner and Jäckle-Sönmez 1989; Bijman and Nijkamp 1988). Many studies suggest that environmental policy will have positive employment effects not only in abatement and in the eco-industry but in the economy as a whole (Deutsches Institut für Wirtschaftsforschung 1994; OECD 1997). We should, however, realize that in our approach environmental policy implies moving up the transformation space (Fig. 3-3) thus reducing the attractiveness of pollution-intensive activities where the rate of return and employment will fall. In that interpretation, environmental policy is a negative supply shock for some sectors. Under static conditions, environmental policy will only be associated with full employment if the real wage falls.

Evaluation of Environmental Quality

In this section we discuss some approaches that have been offered for the determination of the benefits of environmental policy. We focus on the evaluation problem. The main approach is to determine which services the environment provides to households and firms. These services are considered as commodities (commodification of environmental services). A method must then be found to determine the value of these commodities in the utility functions of households and in the production functions of firms. Only those functions can be taken into consideration for the value of the environment that relate to the environment as a public good. Functions of the environment as a receptacle of wastes cannot be used to determine the environment's value as a public good. Services can relate to different aspect: the value of actual use (use value), the option value of use in the future (option value of use) or the existence of the environment, irrespective of actual or future use (existence value). The alternative is to start from information on the extent of physical damages; the damage function is the negative version of the utility function. Procedures used for evaluation are: i) direct elicitation of preferences through markets, ii) willingness-to-pay analysis, iii) household production functions and iv) hedonic price analysis (Braden, Kolstad and Miltz 1991, Kolstadt 2000). All these procedures base environmental evaluation on individual preferences.

Market Prices

The usual method of evaluating commodities starts from their market prices. Market prices tell us how much an individual is willing to pay for a commodity or, from a different perspective, the opportunity costs that he is willing to forgo for a good. The individual consumer derives a consumer surplus from a good (and a service) above the market price he pays. If market prices express individual preferences then one can assess the value of a commodity through the consumers' purchase and demand behavior. Because environmental quality is a public good, market prices do not exist for emissions. Market prices, therefore, can be used only to a limited extent, namely, in those cases where markets provide goods similar to environmental quality, such as "private botanic gardens" (entrance fee; compare cost evaluation below). In some cases markets may be established, for instance when licences to pollute or licences to hunt are auctioned off. These markets allow to elicitate the preferences to use the environment as a receptacle of waste or for hunting. Note, however, that the evaluation problem is not really solved, namely how much environmental quality or how much wildlife is wanted. Thus, markets can only elicitate environmental preferences if new property rights are introduced. These property rights often do not cover the public-goods aspect of environmental quality.

Willingness to Pay

The willingness-to-pay analysis tries to determine how many dollars one is willing to pay for an improvement in environmental quality. Environmental preferences are revealed in interviews or by way of questionnaire. By asking for the willingness to pay for varying levels of environmental quality, we obtain a relation between the environmental quality wanted and the individual's willingness to pay. We can assume that the willingness-to-pay function is downwardsloping. By summing the willingness to pay of all individuals, we obtain the total value of a given environmental quality for society.

Applying the willingness to pay often relates to a hypothetical scenario, for instance a better air quality or the improvement of water quality. The approach therefore is labeled contingent valuation method. It refers to a change in the use value or the option value.

The willingness to pay of an individual depends on a set of factors such as his attitude toward society, the level of applicable information available, spatial extent of the public good, frequency and intensity of use, and income. For instance, the level of information about the effects of environmental pollution plays an essential role. It can be expected that an individual who is better informed about environmental damages, *ceteris paribus*, has a higher willingness to pay. In this context, it is clear that a precondition for effectively utilizing the individual willingness-to-pay approach is that the respective individuals must know the damage function. He has to know what kind of damages are caused by a given quantity of pollutants: injuries to health and the ecology, influences on the consumption good "environment' on production, and on property values. Furthermore, the willingness to pay is different depending on the type of the considered commodity. Several public goods are bound spatially; some pollution can be limited to a single area. The smaller the space occupied by a public good, the easier it is to obtain individual contributions to support it. In this case, the public good is a group good. A dump at the outskirts of a village can easily be removed by sharing the operation costs; however, the willingness to pay in order to prevent a deterioration in the atmosphere will be relatively small. If this thesis is correct, it can be expected that global public goods, such as the atmosphere, will be undervalued.

The willingness to pay also depends on the type of use and the intensity of the needs. Which person living upstream is willing to pay for the purification of wastewater when he does not use it as drinking water anymore? One can also imagine some groups for whom it is more important to have a certain environmental quality than others. Heart and tuberculosis patients, or people suffering from bronchitis, will assign a higher priority to air containing a smaller sulfur dioxide content than will healthy people who are not so blatantly affected by the quality of the surrounding air.

The willingness to pay also differs with income and wealth. On the one hand, one can hold the thesis that high-income recipients can compensate for worse environmental quality through private goods. On the other hand, one can expect that persons with higher income will deem the good "environment" more important than lower-income groups. Furthermore, the possibility of substituting private goods for poor environmental quality is limited.

The central problem of the willingness-to-pay approach is the fact that individuals can intentionally distort their answers because environmental quality is a public good. Individuals can take the position of the free rider. The interviewee can intentionally falsify his answers. For example, he can state a value which is too low when he fears that the poll may be the basis for later charges or, conversely, indicate a too high value in order to emphasize a certain program. In contrast to parting with income when an individual acquires a private good, willingness-to-pay statements for public goods are costless and rely on intentions, ideal or hypothetical circumstances (Braden and Kolstad 1991; Kolstad 2000). Thus, the validity of the willingness-to-pay approach is doubtful indeed.

The intensity of the above distortion depends on several previously mentioned factors such as attitudes toward society and the spatial expansion of the environmental good. It is also influenced by the method by which the supply of environmental quality is financed; for example, whether funds for financing environmental policy are raised by general taxes or according to the individual's willingness-to-pay statement. This point is raised again in the analysis of social choice mechanisms (see below).

Instead of interviews and questionnaires experiments may be used to reveal the preferences of individuals.

Evaluation of Costs: Household Production Functions

Another measure of the evaluation of environmental quality is obtained by determining those costs which a person will tolerate in order to gain a better environmental quality.

Such a cost evaluation can also be performed for public-consumption goods such as national parks; for example, one can determine which journey and overnight accommodation costs individuals are willing to pay in order to enjoy a national park. Another example is avoidance cost, for instance using air filters, water purifiers and noise abatement measures. In these cases, the household can produce a substitute or complement of the environmental good. This is the household production function approach.

Cost evaluation has also been proposed for cases where one's health is endangered. Assume that the damage function shows a relationship between pollutants and days of illness, or illness probabilities. In this case, the social costs of the illness can be approximated by doctors' fees, medical costs, hospital costs, as well as lost income. These costs are interpreted as the lowest value attributable to the health damage. In a similar way, when death is caused by environmental damage, such cases are deemed to represent forgone income. The reader may judge for himself whether this position is tenable.

Note that in the case of travel cost, environmental quality is implicitly evaluated by individual decisions. If cost estimates for the restoration of environmental quality are based on targets set by the government, as in the case of emission norms for firms, these restoration costs cannot be considered to be the accurate indicator of environmental-quality evaluation. The reason is simple. We cannot fix a target, specify its opportunity costs, interpret these costs as an evaluation, and then use benefit-cost analysis to determine the target.

On a formal treatment of the problem how the observation of demand of a private consumption good (and a private input of production) can be used to estimate the willingness to pay for a public good compare Mäler (1985). Maler shows that very specific assumptions are needed to measure the demand for the public good from data on demand for the private good. If the private and the public good are perfect substitutes in a consumption process of the household, we have such a case where the demand for the public good can be measured in terms of cost savings for the private inputs (Mäler 1985, p. 58). On modelling the estimation of benefits also compare Freeman (1985) and Braden and Kolstad (1991).

Hedonistic Price Analysis

Market goods often have implicit attributes with an environmental dimension. Private goods and the public good environment then are complementary to each other. This is especially true for real property with respect to noise, air pollution or amenity of the landscape. Thus, prices for land and buildings can be interpreted as indicators of environmental quality. Within a town with areas of different environmental quality, it can be expected that purchasers prefer areas with a higher environmental quality. This preference should be expressed by an increasing demand for this land and by higher land prices. Of course, we must ensure that environmental quality can be sufficiently isolated as a factor of influence for the land and building values, that is, that the influence of variables such as the type, age, and social status of the housing areas can be evaluated. These studies, however, encounter considerable problems. Since land

and buildings are not often sold, market prices are seldom available. Thus, one must resort to approximate values, for example, tax values.

Another case of hedonistic analysis is migration which may be influenced by environmental quality. As a rule, the income level in metropolitan areas with high industrialization and low environmental quality is higher than in less environmentally damaged areas. The person who emigrates from a low-environmental-quality area "votes" against it as a living place. If one is able to isolate environmental quality as a determinant of regional mobility from other factors causing migration (such as regional wage differences and group adherence), then it is possible to evaluate environmental quality. Forgone wages and removal expenses are indicators of the sum that someone is willing to pay for better environmental quality. If data are available for several areas, one can correlate different levels of environmental quality to the corresponding income levels and reach a conclusion as to what the evaluation for environmental services is.

Individual Preferences and the Pareto-Optimal Provision of Environmental Quality

In the previous four sections we assume that the policymaker has an explicit or implicit social-welfare function with which he can determine the desired environmental quality. The existence of such a welfare function can be doubted once we require certain properties. Benefit-cost analysis also poses considerable evaluation problems. In the following analysis, we want to base environmental policy on individual preferences, not on the preference function of an omnipotent policymaker. Given individual preferences, what is the optimal environmental quality? In a first step, we assume that individual preferences can be revealed. Later, we ascertain which institutional arrangements enable this to be accomplished.

If we base the determination of optimal environmental quality on individual preferences, we can return to Eq. 4.5. There the maximization problem in the case of Pareto optimality is discussed. We use the optimality conditions stated in Appendix 4-B. Divide Eq. 4.6a by $W_1^{1'} = \lambda^2 W_1^{2'}$. Then we have[7]

$$\frac{\lambda_U}{W_1^{1'}} = \frac{W_U^{1'}}{W_1^{1'}} + \frac{W_U^{2'}}{W_1^{2'}}$$

Using Eq. 4B.2 to 4B.4 and 4B.9,[8] we have

$$\frac{1}{-G'(H_1'+F_1^{r'}/F_1')} = \frac{W_U^{1'}}{W_1^{1'}} + \frac{W_U^{2'}}{W_1^{2'}} \tag{5.7}$$

[7] An inner solution is assumed.

[8] Note that $W_1^{1'} = \lambda_1 = \lambda_S H_1' + \lambda_{Q_1} = \lambda_S H_1' + \dfrac{\lambda_R}{F_1'} = \lambda_S \left(H_1' + \dfrac{F_1^{r'}}{F_1'} \right)$.

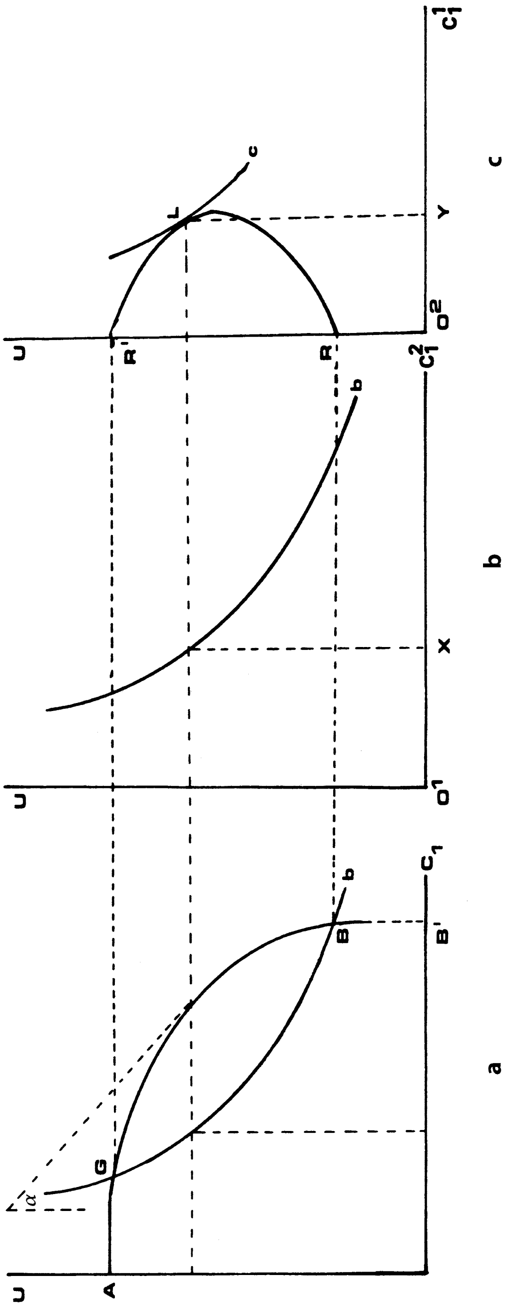

Fig. 5-4. Pareto optimum of environmental allocation

Equation 5.7 describes a property of optimal allocation. The term on the lefthand side defines the marginal rate of transformation $\mathrm{MRT}_{Q_1U}(dQ_1/dU)$ for the case when sector 2 does not produce. This follows from Eq. 3A.4. The right-hand side is the sum of the marginal rates of substitution for the two individuals between environmental quality and the private good, $\mathrm{MRS}^j_{Q_1U}(dQ^j_1/dU)$. Note that for an indifference curve we have $dW^j = 0$, that is, $dQ^j_1/dU = W^{j\prime}_U/W^{j\prime}_1$. Consequently, Eq. 5.7 can be expressed as

$$\mathrm{MRT}_{Q_1U} = \mathrm{MRS}^1_{Q_1U} + \mathrm{MRS}^2_{Q_1U} \tag{5.8}$$

The marginal rate of transformation indicates the opportunity costs of one unit of environmental quality in terms of commodity 1. An additional unit of environmental quality implies some loss of private goods. The marginal rate of substitution indicates which marginal utility from good 1 the individual can give up for marginal utility from environmental quality, given a constant utility level. The marginal rate of substitution denotes the willingness to pay of the individual according to his (truly revealed) preferences. A Pareto optimum of environmental allocation requires that the opportunity costs of one unit of environmental quality be equal to the aggregated willingness to pay of the individuals of a society. Eq. 5.8 is Samuelson's well-known summation condition for public goods (Samuelson 1954).

In Fig. 5-4, the Pareto-optimal provision of environmental quality is illustrated. We assume that only one private good, commodity 1, is produced and consumed so that the transformation space of Fig. 3-3 is reduced to curve $AGBB'$ in Fig. 5-4a. This curve results from a cut through the transformation space for R_2, $R'_2 = 0$. In Fig. 5-4b, curve b denotes an indifference curve of individual 2. Pareto optimality requires that individual 2 remain on an arbitrarily chosen indifference level. We plot curve b in Fig. 5-4a. Then the lense above (and on) the indifference curve b and below (and on) the transformation curve represents the feasible consumption space for individual 1. This feasible consumption space is shown by curve RR' in Fig. 5-4c. Observe that if we let individual 2 obtain his indifference level b, the range of environmental quality which will be provided is given by RR'. Pareto optimality requires that, for a given indifference level b of individual 2, the utility of individual 1 be maximized. This is the case at point L where the consumption space feasible for individual 1 reaches the highest indifference curve of individual 1.

In Fig. 5-4a, the marginal rate of transformation $\mathrm{MRT}_{Q_1U} = dQ_1/dU$ is measured by $tg\alpha$. Similarly, angles have to be drawn for the marginal rates of substitution; they are, however, not shown in order not to overload the diagram. The slope of curve RLR' is given by $\mathrm{MRT}_{Q_1U} - \mathrm{MRS}^2_{Q_1U}$. This follows from the construction of curve RLR'. In point L we have

$$\mathrm{MRT}_{Q_1U} - \mathrm{MRS}^2_{Q_1U} = \mathrm{MRS}^1_{Q_1U}$$

which is equivalent to Eq. 5.8.

In the Pareto optimum, both individuals use the same environmental quality as a public good; O^1X denotes the quantity of the private good used by individual 2, and O^2Y indicates the quantity used by individual 1. Figure 5-4 is an illustration of the problem stated in Eq. 4.5 along with some of its implications.

From welfare economics we know that the Pareto criterion results in only a partial ranking of economic situations. Assume, for instance, that we begin with a lower indifference curve $b' < b$ for individual 2. Then the consumption space RR' feasible to individual 1 would be larger and the Pareto-optimal point L' would be situated northeast of L. We can imagine a set of Pareto-optimal situations that can be defined as the utility frontier.

Thesis of Market Failure

A Pareto-optimal provision of environmental quality requires that the aggregated willingness to pay be equal to the opportunity costs of environmental quality. Equation 5.8 can be expressed in terms of prices. The marginal rate of transformation MRT is identical to the relationship of marginal costs MC; the marginal rates of substitution are identical to the relative prices, so that we have

$$\frac{\mathrm{MC}_U}{\mathrm{MC}_{Q_1}} = \frac{P_U^1}{P_{Q_1}} + \frac{P_U^2}{P_{Q_1}} = \frac{P_U^1 + P_U^2}{P_{Q_1}} \tag{5.9}$$

We know that in a competitive equilibrium the price for private good 1 is identical for all individuals and equal to marginal costs. Then Eq. 5.9 requires that prices for the public good "environmental quality" be differentiated among individuals. The sum of individual prices (individual evaluation) must equal the marginal costs of production of the public good. The same conditions follow from Eq. 4.6 or 4.10.

It is obvious that the market cannot find a set of differential prices for environmental quality. This is because environmental quality is a public good. Once a unit of this good is provided for one individual, it is also available to another individual. Therefore, it is impossible to exclude the other individual. For instance, consider Fig. 5-4. Once a range RR' of the public good is provided for individual 2, it is also available for individual 1.

Lindahl Solution

The Lindahl solution (Head 1974; Lindahl 1919; Roberts 1974) assumes that personalized prices for the public good "environmental quality" can be established. Individuals truly reveal their preferences, and either an environmental agency or an auctioneer sets personalized prices for each individual according to the individual's willingness to pay. Each individual contributes to the costs of the public good according to his marginal utility multiplied by the quantity of environmental quality used.

Alternative Implementations

There are three ways to interpret the Lindahl solution in an environmental context:[9]

1. Consumers pay individualized prices p^j_U for environmental quality; the receipts are used to pay a subsidy to firms per unit of abated emissions.
2. Consumers pay individualized prices p^j_U. The receipts are used for pollution abatement by public agencies such as water cooperatives.
3. Firms pay an emission tax per unit of pollution according to the polluter-pays principle. Tax receipts are used to pay individualized compensations. Then prices p^j_U are negative.

In our approach, this last interpretation is used. Our application is consistent with chapter 4 where we assume that tax receipts are transferred to households. Here we specify the rules according to which compensation takes place.

Decision of Consumers

We assume that consumers are compensated for environmental degradation. Let U^j indicate the actual environmental quality desired (used) by individual j. So $U^{\max} = G(S)$ for $S = 0$ defines the maximal environmental quality, that is, ecological paradise. Then

$$U^{Pj} = U^{\max} - U^j \tag{5.10}$$

indicates the environmental degradation tolerated by individual j. Let $p^j_U \leq 0$ indicate the individualized price per unit of pollution. Then the decision of the household is to maximize utility subject to the budget constraint with given prices, including $p^j_U \leq 0$:

$$\max\ W^j(C^j_1, C^j_2, U^j)$$

such that

$$\sum_i \tilde{p}_i C^j_i \leqslant Y^j - p^j_U U^{Pj} = Y^T$$

$$Y^j = \tilde{r} R^j + \sum_i \theta^j_i \Pi_i \tag{5.11}$$

[9] On the Lindahl solution in an environmental context, compare Pethig (1979, 1980).

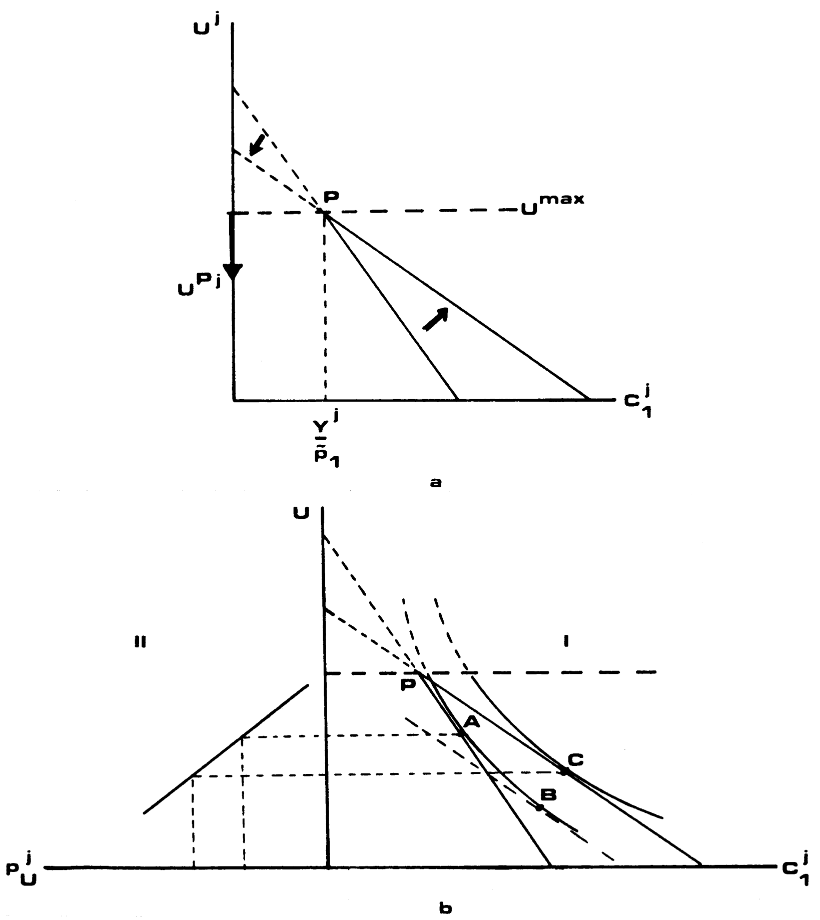

Fig. 5-5. Household optimum

Now, R^j is the initial resource endowment of household j, and θ^j_i represents given profit shares of household j with respect to firm i. For a given price vector, income Y^j is given. In the budget constraint, the term $-p^j_U U^{Pj}$ represents compensation payments to individual j. It is an addition to income Y^j. And Y^T is total household income including compensation.

Substituting Eq. 5.10 into the budget constraint and assuming, for simplifying purposes, only one commodity, we find that the budget constraint is

$$U^j \leqslant \frac{\tilde{P}_1}{p^j_U} C_1 - \frac{Y^j}{p^j_U} + U^{\max} \tag{5.12}$$

The budget constraint is illustrated in Fig. 5-5a. The budget constraint has a negative slope $\tilde{p}_1/p^j_U$. We have

$$C_1 = 0 \Rightarrow U^j = U^{\max} - \frac{Y^j}{p^j_U}$$

$$U^j = 0 \Rightarrow C_1 = \frac{Y^j}{\tilde{p}_1} - \frac{p^j_U}{\tilde{p}_1} U^{\max}$$

We know that $U^j \leq U^{\max}$, so that a section of the budget constraint is not relevant. If a higher compensation is paid, that is, if p^j_U rises in absolute terms, then the slope becomes lower and C_1 becomes larger (for $U^j = 0$). The budget constraint turns around point P as indicated in Fig. 5-5a. Observe that for $U^j = U^{\max}$, the budget constraint passes through point P since we have $C^j_1 = Y^j/\tilde{p}_1$ independent of the compensation rate.

In Fig. 5-5b the willingness-to-pay function of the household is derived. For a given compensation rate, point A in quadrant I represents a household optimum. If compensation is increased, the new optimum point is C. We know that the change in demand can be split into a substitution effect A-B and an income effect BC. Whereas the substitution effect always implies a reduction in demand for environmental quality, with increased compensation the income effect may work the other way. Increased compensation means a higher total income Y^T, and higher income may result in a higher demand for environmental quality. We assume here that the income effect does not outweigh the substitution effect. Then we have this: An increase in the compensation rate implies that a household tolerates more degradation U^P or that the desired environmental quality decreases. The relationship

$$U^j = \psi(p^j_U) \quad \text{with} \quad \frac{dU^j}{d\,|p^j_U|} < 0 \tag{5.13}$$

is the willingness-to-pay function shown in quadrant II of Fig. 5-5b. So far, we have interpreted Eq. 5.13 by starting from $U^{\max}$ and asking for the tolerated degradation. We can also start from zero environmental quality and ask for the household's willingness to pay with respet to environmental improvement. The willingness to pay is high for a low environmental quality, and it becomes smaller as environmental quality improves.

Definition of the Lindahl Equilibrium

An allocation A and a price vector P are a Lindahl equilibrium if (1) (C^j_1, C^j_2, U^j) is a solution to the maximization problem of households as described in Eq. 5.10, (2) (Q_i, R_i, R^r_i, S) is a solution to the maximization problem of firms as stated in Eq. 4.8, and (3) the following conditions hold:

$$
\begin{aligned}
Q_i &= \sum_j C_i^j \\
\bar{R} &= \sum R_i + \sum R_i^r \\
U^1 &= U^2 = U \\
S &= \sum S_i = \sum S_i^p - \sum S_i^r \\
-p_U^1 U^1 - p_U^2 U^2 &= -(p_U^1 + p_U^2) U = z \sum S_i \quad \text{with} \quad U = G(S)
\end{aligned}
\tag{5.14}
$$

Assume that an auctioneer sets prices z, p_U^j for the economy. Condition 3 indicates the constraints that the auctioneer has to observe. The first two conditions are the usual equilibrium conditions for the commodity markets and the resource markets, respectively, and $U^1 = U^2 = U$ requires that prices be set in such a way that both individuals use the same environmental quality. This is the public-good constraint relevant for the auctioneer. Since U determines S, that is, the tolerable quantity of emissions, it is required that the supply of emission "rights" be identical to the demand of polluters. Finally, the budget must be balanced. The contribution of both individuals must be equal to the costs of producing the public good. Prices for the public good are personalized.

Graphical Illustration

In Fig. 5-6, we illustrate the basic idea of the Lindahl solution.[10] In quadrant III of Fig. 5-6a, the willingness-to-pay functions for environmental quality U of individual 1 (curve TT') and individual 2 (curve VV') are shown. Curve $V'PW$ denotes the aggregated willingness to pay for alternative environmental qualities. Quadrant IV shows the damage function $U = G(S)$, as explained in Eq. 3.5. As a result of this function, willingness to pay can also be related to emissions S. Quadrant II serves to transform the price p_U an emissions tax z, with $tg\alpha = z/p_U$ (compare Pethig 1980). Let e_S indicate a unit (pound) of pollutants, and let e_U indicate a unit of environmental quality. Then $tg\alpha$ has the dimension

$$\frac{\$/e_S}{\$/e_U} = \frac{e_U}{e_S}$$

Thus, $tg\alpha$ is merely a conversion factor.

[10] Alternative graphical illustration is the Kolm-Edgeworth box (Malinvaud 1971; Pethig 1979). Also compare Mäler (1985).

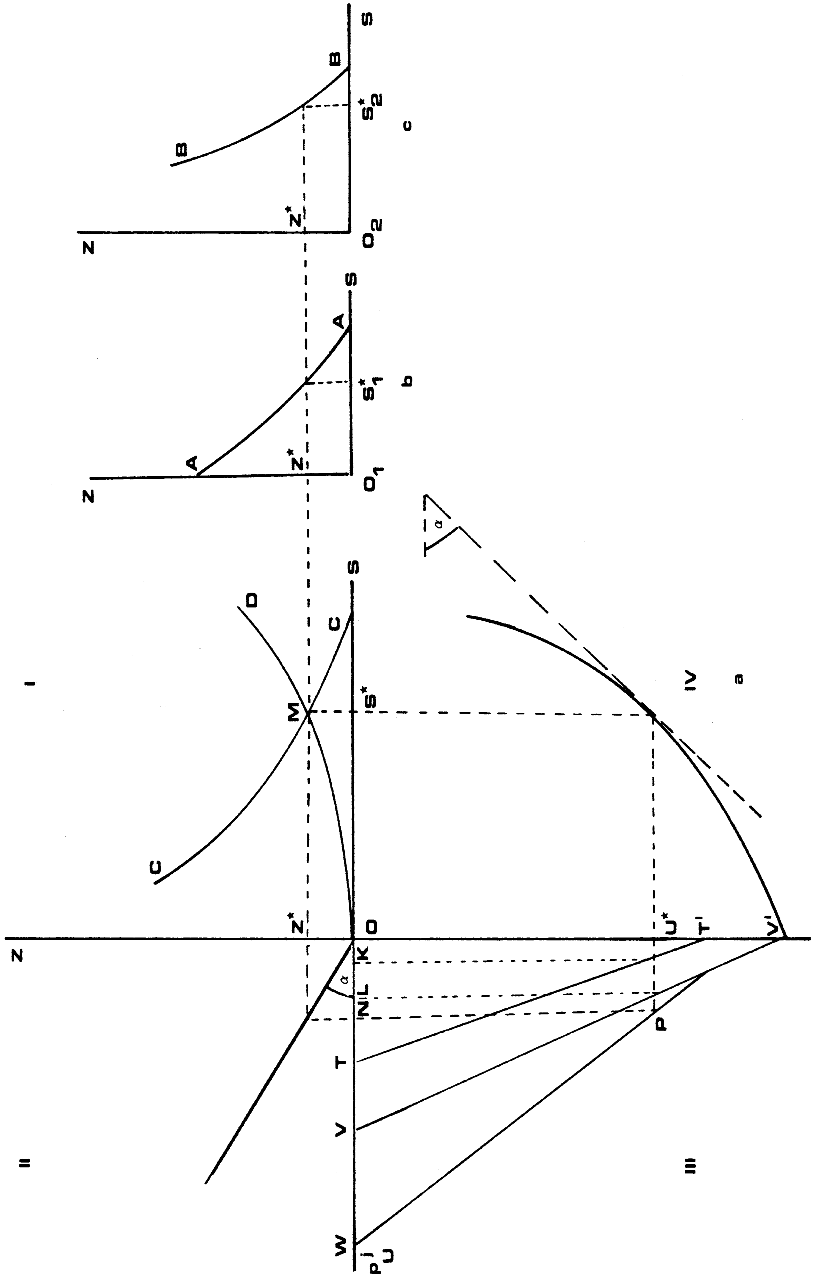

Fig. 5-6. Lindahl equilibrium

Curve OD denotes the marginal evaluation of pollutants by both individuals.[11] There is a relatively high willingness to pay for an improvement in environmental quality if environmental quality is low, for example, if many pollutants exist. The willingness to pay becomes smaller for higher levels of environmental quality (lower levels of pollution). If we interpret the S axis in quadrant I from point C toward point O, the S axis indicates abated pollutants; consequently, curve DO can also be interpreted in terms of prevented damage.

Curve CC in quadrant I denotes the marginal costs of abatement (compare Fig. 4-1). This curve is aggregated horizontally from the cost curves AA of firm 1 (Fig. 5-6b) and BB of firm 2 (Fig. 5-6c).

The optimum is found where marginal costs of abatement are identical to marginal prevented damage. Here S^* is the optimal level of pollution, and U^* represents optimal environmental quality with both individuals using the same environmental quality, that is, $U^1 = U^2 = U$. The individualized prices are $p_U^1{}^* = OK$ and $p_U^2{}^* = OL$. We see that these prices differ if the willingness to-pay curves are different. Only if both individuals have identical curves of willingness to pay will we have an identical price for environmental quality.

Whereas the price for environmental quality is differentiated among consumers, the price z for pollutants or emissions is identical for all polluters. The curves of marginal abatement costs of firm 1 (Fig. 5-6b) and firm 2 (Fig. 5-6c) are given. By aggregating both cost curves, we obtain curve CC which can be interpreted as the marginal-cost curve of abatement for the economy. The optimal level of pollution is determined where marginal costs of abatement and marginal prevented damage are equal. The optimal emission tax is z^*.

Because of the construction of the aggregated curve of marginal abatement costs, we know that $S_1^* + S_2^* = S^*$. Also we know that total tax receipts z^*S^* are identical to the sum of individual tax payments by firms $z^*S_1^* + z^*S_2^*$. The budget constraint requires that total tax receipts z^*S^* (quadrangle OS^*Mz^*) be identical to total compensation payments OU^*PN.

The auctioneer has to set prices according to the conditions in Eq. 5.14. The individuals must truly reveal their willingness to pay. Also the first quadrant of Fig. 5-6-a and Figs. 5-6b and c can be interpreted as illustrating a pseudo-market of emissions or emission rights. The supply of emission rights OS^* is determined by the political process. The demand ($O_1S_1^*$ and $O_2S_2^*$) is determined by decisions of the firm. In a Lindahl equilibrium, the supply and demand of emission rights are equal.

Figure 5-6 attempts a graphical representation of a general equilibrium. However, the reader should be aware of the fact that some of the curves are drawn for equilibrium variables. These curves can shift if specific variables change. For instance, the marginal-cost curves of abatement assume a given

[11] Curve OD starts at point O for two reasons. First, the curve $U = G(S)$ in quadrant IV has to be drawn in such a way that for $S = 0$ we have $U = U^{max}$. Second, we can expect that the aggregated willingness to pay is zero for U^{max}.

resource price; if this price changes, then the curves will shift. The willingness-to-pay curves of both individuals depend on income that is ultimately determined in a general equilibrium. Also $tg\alpha = dU/dS$ in quadrant II is given by the equilibrium value $G'(S^*)$.

Mechanisms of Social Choice

The Lindahl procedure can be viewed as a social choice mechanism for environmental goods. It represents, in fact, the dual approach to a competitive economy with private goods. In markets for private goods the commodity price is uniform, but quantities demanded vary across consumers. In the Lindahl approach, the public good quantity is the same, but (Lindahl) prices vary across consumers.

The Lindahl mechanism is attractive because it takes individual preferences into account in such a way that a Pareto-optimal allocation is achieved when it is presumed that individuals truly reveal their preferences. But unfortunately, individuals can be shown to have strong incentives not to reveal their preferences (free-rider behavior). Due to this incentive incompatibility, the Lindahl mechanism does not solve the problem of allocating environmental goods efficiently.

In view of this unsatisfactory performance of the Lindahl mechanism it would be desirable to have social choice mechanisms that are both responsive to individual preferences and incentive compatible. Are there institutional arrangements for collective decision making that involve a consistent aggregation of individual preferences? Is it possible to design efficient social mechanisms that are immune to strategic manipulation by preference misrepresentation? In what follows we first investigate the preference aggregation issue and specify its implication with the help of the majority voting rule. Then we focus attention on the preference revelation issue with special reference to demand revealing processes.

The Aggregation Problem

On the conceptual level, each social choice mechanism can be considered as implying rules how to transform individual preferences into a "preference ordering of society" (which is then applied to select a particular element from the set of feasible alternatives). Different preference aggregation procedures are conceivable, but not all of them seem to reflect the underlying individual preferences in a reasonable or desirable way.

Arrow (1951) considered the following five requirements (axioms) for the aggregation process as reasonable (see e.g., Inman 1987, 682 n.):

1. Preference aggregation is feasible for all possible combinations of complete and transitive individual preference orderings of the alternatives (unrestricted domain).

2. If everyone prefers some alternative x to another alternative y, then society prefers x to y (Pareto optimality).
3. No individual has full control over the social choice process (nondictatorship).
4. The social ranking of each pair of alternatives depends only on the individuals' orderings over those two alternatives, and not on individual orderings over other alternatives (independence of irrelevant alternatives).
5. Preference aggregation leads to a complete and transitive social ranking of alternatives (rationality).

Each of these five axioms seems to be a reasonable or plausible restriction for social choice mechanisms. But unfortunately, Arrow's impossibility theorem states that there is no social choice process which satisfies these five axioms simultaneously. For example, if there is a social choice mechanism satisfying axioms 1–4, this mechanism implies an incomplete or intransitive social ranking of alternatives. This very general and disappointing conclusion about the impossibility of consistent preference aggregation cannot be avoided unless at least one of the axioms 1–4 are relaxed. In what follows we show the relevance of the Arrow impossibility theorem for the majority voting rule.

Majority Voting

Voting can be interpreted as a social choice mechanism in which public institutions or the public provision of goods and services, e. g., environmental quality, are determined with the help of individual preferences. The majority voting rule states that out of two alternatives, x is adopted by society rather than y, if and only if the majority prefers x to y. Hence this rule implies the aggregation of individual preferences in the sense that the "preference of society" is to prefer x to y whenever a majority of voters exhibits this preference.

More specifically, define the outcome of the majority rule for a set of three or more alternatives as follows: Start with a vote between any pair of alternatives. Take that one which wins the majority of votes to continue this process of pairwise comparisons with the respective winners until only one unbeated (and unbeatable) alternative is left, called the Condorcet winner or the *majority voting equilibrium*. In formal terms, an alternative a from a set A of alternatives constitutes a majority voting equilibrium, if there is no alternative $\alpha' \in$ A which is preferred to a by a majority of voters.

Due to Arrow's impossibility theorem we know that the majority rule satisfying the axioms 1–4 does not satisfy the rationality axiom 5. As a consequence the majority rule does not produce a Condorcet winner, in general. In other words, if one does not introduce a stopping rule, no unique outcome emerges from the pairwise comparisons (voting cycles) because the implied preference aggregation process leads to intransitive "preferences of society". This paradox of voting has already been pointed out by Marquis de Condorcet in the 18th century.

In order to establish consistency of aggregation at least one of the axiom 1–4 must be relaxed. One possibility is to loosen the axion of unrestricted domain by restricting the feasible set of individual preference orderings to the set of those orderings which yield single-peaked net-benefit functions specifying the consumer's utility from environmental quality after his cost share of providing that good is already taken into account. To illustrate this concept, consider the simple case in which the consumer's utility is $W^i(C, U)$ from consuming x units of a private consumption good and u untis of environmental quality. Let his budget constraint be given by $C + c^i U = y^i$, where y^i denotes exogenous income and c^i the consumer's cost share per unit of environmental quality assuming that $\Sigma_i c^i = c$ is the constant cost for one extra unit of environmental quality. In this model, the consumer's net benefit is given by

$$N^i(U) := W(y^i - c^i U, U)$$

Under standard assumptions, this function N^i is strictly concave and hence "single peaked" Graphically, it can easily be derived from the indifference curves of function W^i and the budget line in Fig. 5-7. The single-peakedness condition turns out to be sufficient for avoiding voting cycles. In other words, with this condition the majority rule leads to a unique collective decision which is called the majority voting equilibrium.

The determination of environmental quality with majority voting is illustrated in Fig. 5-8. In this figure three different voters with different net-benefit curves are considered. The voters are ordered according to the value of U associated to the peak of their net-benefit curve. If voter i could decide on the level of environmental quality by himself, he would choose U^i (given the cost-sharing rule implicit in his net-benefit curve). It is easy to see that the

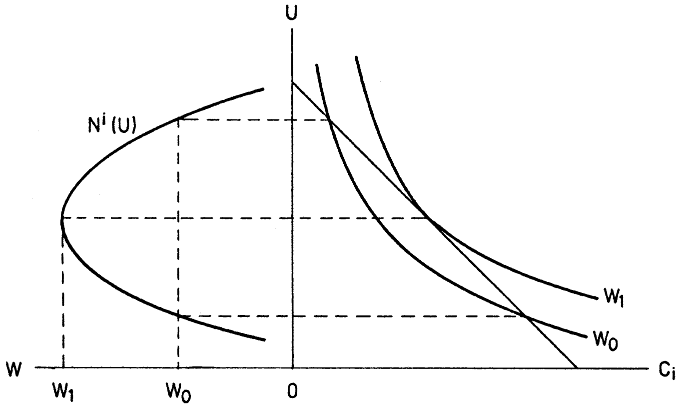

Fig. 5-7. The net-benefit function of the consumer

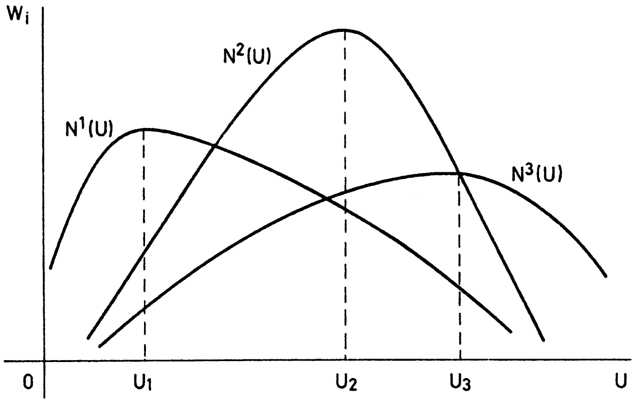

Fig. 5-8. The median voter

alternative U^2 gets the majority of votes in pairwise comparisons with any $U \neq U^2$ (in particular also with U^1 or U^2). Hence U^2 is the (unique) majority voting equilibrium. Observe that individual 2 is the decisive voter because the majority rule selects individual 2's best choice U^2. In fact, it is a general result for any number of voters that the decisive voter is always the median voter, i.e., the one whose net-benefit peak is the median of all voters' net-benefit peaks.

In the preceding discussion we assumed constant marginal cost of providing environmental quality which is an unrealistic (partial equilibrium) assumption. In what follows we indicate the additional complexities of a model in which this assumption is relaxed. With increasing marginal cost of environmental quality we must place majority voting into a general equilibrium framework in which all private and public decisions are genuinely interdependent. In such a model markets must clear and the budget of the environmental agency receiving payments from consumers and giving subsidies to firms for emission abatement (or vice versa) must be balanced.

Consequently, as long as these conditions of market clearing and balance of the budget are not satisfied, the price for environmental quality will change. Then the net-benefit curves in quadrant II in Fig. 5-7 will shift with a change in price. After environmental quality is determined by the median voter, the costs of producing the public good are given. Since costs and receipts from payments by consumers must balance, a new price must be set if the balance does not exist. Then new net-benefit curves must be constructed. This may cause another voter to become the median voter. We can conceive of a *tatonnement* process by which the sum of prices eventually equals marginal costs of the environmental quality. Note that the willingness-to-pay curve may shift in the *tatonnement* process with such variables as allocation, prices, and income. Dudenhöfer (1983) elaborated a general equilibrium model in which majority voting determines environmental quality and in which all the above-mentioned feedbacks are included.[12]

Let us now turn to the *normative properties* of majority voting as a mechanism of social choice. May (1952) formalized the individual vote for one out of two options (here: environmental qualities), q_1 and q_2, by introducing a choice variable e_i defined by

$$N^i(U_1) - N^i(U_2) \left\{ \begin{matrix} > \\ = \\ < \end{matrix} \right\} 0 = e_i = E^i(U_1, U_2) = \left\{ \begin{matrix} 1 \\ 0 \\ -1 \end{matrix} \right\}$$

He then modelled the social choice mechanism in an abstract way as a mapping from the vectors of individual choices $e := (e_1, \ldots, e_i, \ldots, e_n)$ into a social decision e_s. May considered it desirable for such a mapping to satisfy the following properties:

1. The social decision is defined for all vectors of individual choices and is unique (existence and uniqueness).
2. The social decision is independent of who among the vectors has a specific preference (anonymity).
3. The social decision is independent of the description of the alternatives (neutrality).
4. If the ranking of alternatives q_1 and q_2 by an individual is reversed, the ranking of society is reversed if the society was indifferent before (positive reaction or sensitivity).

It turns out that the majority voting rule satisfies these four properties (May Theorem). This can be considered a basis for recommending the majority rule. But this rule has some other (normative) properties which appear to make it somewhat less attractive.

Although the single-peakedness condition secures a consistent collective decision, the majority rule will not, in general, lead to a Pareto-optimal resource allocation, as was the case with the Lindahl procedure. Moreover, it is not generally true that the majority rule is individually rational or incentive compatible (Mueller 1986). All this casts considerable doubt on the efficiency of the majority rule even under the condition of single-peaked preferences which allowed to escape the more devastating consequences of Arrow's impossibility theorem, namely the nonexistence of a majority voting equilibrium.

Recalling this important role of the single-peakedness assumption begs the question as to how restrictive or realistic this assumption is. It can be shown to be a fairly mild restriction in one-dimensional budget problems, but single-peakedness is very unlikely to be expected in social choice situations where alternatives are ordered on two or more dimensions.

[12] Besides single-peakedness, Dudenhöffer (1983) needs a strong assumption on the homogeneity of preferences. The majority of consumers have the same characteristics (p. 73).

Other Forms of Voting

Simple majority voting is just one specific voting rule. Many other forms of voting exist such as qualified majority (for instance for changes in the constitution) or more generalized forms of majority voting being extended from the two-alternative to the multialternative case. Other rules are the plurality rule where the alternative favored by the largest number is chosen, possibly with a runoff, preferential voting with voters ranking alternatives, or even unanimity rules. Voting may take place under different institutional settings. For instance, a referendum concerns one specific issue and, as practised in the United States or in Switzerland, a definite public good is voted upon; very often the costs of the public good are indicated, including the apportioned cost per citizen. For example, in the city of Davos in Switzerland, voters were asked whether they supported a new water-purification facility with costs being attributed to house-owners. In such cases the voter can only say yes or no; the political fight among different groups for a yes or no vote may be considered as a way of revealing preferences.

Logrolling or vote trading means that alternatives are no longer independent of one another. A group of voters forms a coalition with another group, and they trade votes, one group lending votes to the other on one issue and receiving support on another issue in return.

Voting may also be studied in the context of political parties attempting to maximize votes and competing with each other, with bureaucracy and interest groups playing an important role. The reader is referred to the literature of public choice.

Finally, the legal system is instrumental in revealing preferences of a society, for instance in protecting the views of specific groups and minorities.

Demand-Revealing Processes

New institutional mechanisms of aggregating individual preferences have been proposed which explicitly attempt to reveal the willingness to pay of each person. One such proposal is the Vickrey-Clarke tax (Vickrey 1960; Clarke 1971; Tideman and Tullock 1976). The simplest way of describing this tax scheme is to start from a status quo situation, say A, and to consider the social choice problem of moving from A to an alternative B. (The Vickrey-Clarke procedure can also be applied to continuous social choice.) Every voter is asked to state his willingness to pay for moving from A to B, where it is presupposed that everybody knows his cost share for the transition from A to B. Observe that in contrast to simple voting with yes or no (which implies the individual rank-ing of alternatives only) this voting procedure is more demanding in that it re-quires to report preference intensities.

Let S_B denote the sum of the reported net willingness to pay of all individuals for moving from A to B. The society chooses the alternative B if the reported aggregate net willingness to pay for A is greater than zero: $S_B > 0$.

With incomplete information of individual preferences the public decision-maker does not know whether the individuals report their net willingness to pay truthfully. Unfortunately, it can be shown that, in general, the voters do have an incentive to misrepresent their preferences, so that the alternative B may be chosen even though the status quo option A is socially preferable in the sense that the associated true aggregate net willingness to pay for B is less than zero.

The Vickrey-Clarke tax is designed to ensure that all individuals find it in their own interest to report their true willingness to pay. This tax is imposed on so-called pivot voters only, i.e., on those who reverse the social choice of an alternative by the willingness to pay what they report. More specifically, consider the voter i and denote by S_B^{-i} the net willingness to pay reported by all voters except i. If $S_B > 0$ but $S_B^{-i} < 0$, then voter i has to pay the Vickrey-Clarke tax S_B^{-i}. Clearly, this tax represents the net loss of all individuals except i which these individuals suffer when alternative B is chosen. Imposing the tax S_B^{-i} on voter i implies, therefore, that this voter has to bear the social cost of his pivotal decision.

Suppose the Vickrey-Clarke tax is implemented and voter i is in a situation such that $S_B^{-i} < 0$. Then he has the option to leave the result as it would have been without his vote or to change the result in which case he has to bear the tax S_B^{-i}. A distorted answer would not be in voter i's self-interest for the following reason. If his true net willingness to pay for the transition from A to B is lower than the reported aggregate net valuation of the others (S_B^{-i}), then voter i would prefer to give a nonpivotal answer leaving the result as it is without his vote. Hence there is no incentive for him to misrepresent his preferences. However, when voter i's net valuation of the transition to situation B is greater than the other's reported aggregate net valuation (which is assumed to be negative), then it is voter i's self-interest to turn the result around with his vote. Playing down his true preference for the transition would make him worse off than telling the truth. Thus, the Vickrey-Clarke tax presents a social choice mechanism which is strictly individually incentive compatible in the sense that truth telling is a dominant strategy for every individual. (This mechanism is not immune to preference manipulation by coalitions of voters, however.)

The Vickrey-Clarke tax is therefore a process for revealing public-goods demand. In some sense, this procedure escapes, in fact, from Arrow's general result of the impossibility of consistent aggregation of individual preferences. But closer inspection shows that a price has to be paid for this escape. Firstly, one has to give up the axiom of unrestricted domain: The procedure only works as described above if all individuals' utility functions belong to the special class of quasi-linear functions which are not empirically relevant. Another drawback is that the revenues generated by the Vickrey-Clarke tax which are nonnegative under suitable specifications of that tax cannot be redistributed to the individuals without destroying its demand-revealing property. The tax revenue has to be withdrawn from circulation, i.e., it has to be thrown away, which must be considered the cost of demand revelation.

A demand revealing mechanism which does not require to restrict the domain of individual preferences and allows, at the same time, to balance the government's budget (as a precondition for a total as opposed to partial equilibrium analysis) has been introduced by Groves and Ledyard (1977). Pethig (1979) applied the Groves-Ledyard mechanism to the preference disclosure for environmental goods.[13] The mechanism is related to the Vickrey-Clarke tax: Economic subjects inform the environmental agency about their desired environmental quality, thus implicitly reporting to the center their marginal willingness to pay. The environmental agency employs a compensation scheme involving negative or positive payments for individual agents. If an individual deviates from the average reply of all others by demanding, e.g., a better environmental quality, then the compensation scheme implies a tax payment for this individual. Of course, as in the case of the Vickrey-Clarke tax, all individuals will take this compensation scheme into account in their communication process with the environmental agency. This process runs iteratively, eventually resulting in a situation where all individuals want the same environmental quality. This property is also shared by the Vickrey-Clarke procedure, when applied to a continuous social choice problem, but not by the discrete choice version described above and not by elections and referenda. In the latter cases it is not true that the socially chosen environmental quality is at the same time all individuals' most preferred choice (in elections, for example, 50.01 percent decide and all others may be losers). In contrast, the compensation function of the Groves-Ledyard mechanism as well the Vickrey-Clarke tax in the generalized model are strict enough to bring about a harmonization of desires.

Ethical Aspects of Environmental Evaluation

The evaluation of the environment as a public good rests on ethical value judgments. An underlying assumption of social choice is that as a method of reaching decisions in a society we aggregate individual preferences into a value judgment of society. In this way we then come to a decision on environmental issues subject to constitutional constraints. Taking into account the human experience with despotism, dictatorships, and the totalitarian systems of Nazism and Communism, I do not see an alternative to this approach if a dictatorship is clearly to be ruled out. I cannot envision another institutional setting in which a preference of a subset of society takes the place of the aggregation approach.

The mechanism of aggregation may be wanting in several respects. Thus, it does not obtain consistent decisions (Arrow's Impossibility Theorem). Moreover, individuals are confronted to form ethical norms on new phenomena and new options of actions that were not available to them previously. An example is new methods in biotechnology, including the use of human cells to fight illnesses. There cannot be a moral vacuum for new phenomena. Furthermore, it is argued by some that individuals are inadequately informed so that they do not take into account the implications of their decisions, for instance the long-run

[13] The same result is reached in a Lindahl equilibrium. On the practicability of the Groves-Ledyard mechanism compare Mäler (1985, p. 47).

impact on environmental quality. Others point out that individual's preferences are distorted by socialization and advertising so that their preferences are biased in favor of self-interest and against environmental concerns (Sagoff 1998). Another line of reasoning takes the view that ethical values should not only be rooted in humans, but that values and rights should be defined from the point of view of animals and plants to whom moral standing should be given.[14]

One would like to have a universal rule for individual behavior. Such a universal rule would also guide human behavior in situations that are new. Philosophers and religions have described such universal rules. One is Kant's categorical imperative: "Act so that the maxim of your will can be valid at the same time as a principle of universal legislation." Similarly, the ethic of reciprocity requiring that each individual should treat others in a decent manner and in the same way he wants to be treated is a common feature in nearly all religions, ethical systems, and philosophies.[15] The most commonly known version in the Western World is the Golden Rule of Christianity, often expressed as "Do onto others as you would wish them do onto you." The underlying element of this ethic is that every individual shares the same inherent human rights. In a wide interpretation, destroying someone else's living space represents a harm to him/her that one would not like to see done to oneself. All these questions become more important as humankind is becoming increasingly aware of the global interdependence of the planet Earth with respect to global warming (chapter 13).

A pragmatic approach has been taken in this book, namely that the environment or the set of natural conditions defines the human living space. In this functional view, the environment represents a good whose quality humans can influence. It is a restraint for human behavior. Humans have a choice regarding how much environmental quality they want. In this choice, they have to take into account the impact of their behavior. This includes the long-run effects on environmental quality through the accumulation of pollutants over time or the heightened probability of environmental accidents. Information on the damage function therefore is an integral part of ethical issues. Human experience on the long-run effects and learning about these effects explain how a system of norms evolves. To evaluate the impact of an individual action, requires the

[14] It has been pointed out that the Christian faith was a precondition for technological development in that it no longer had personalized gods and goddesses of nature, but in a way abstract deities (Gimpel 1975).

[15] Compare the Greek philosophers "May I do to others as I would that they should do unto me." (Plato), "Do not do to others that which would anger you if others did it to you." (Socrates) and the religions, for instance "This is the sum of duty: Do naught unto others which would cause you pain if done to you" (Brahmanism: Mahabharata, 5:1517), "… a state that is not pleasing or delightful to me, how could I inflict that upon another?" (Buddhism: Samyutta NIkaya v. 353), "Therefore all things whatsoever ye would that men should do to you, do ye even so to them." (Christianity: Matthew 7:12), "Do not do to others what you do not want them to do to you" (Confucianism: Analects 15:23) and "What is hateful to you, do not to your fellow man. This is the law: all the rest is commentary." (Judaism: Talmud, Shabbat 31a).

Table 5-2. U.S. National Ambient Air Quality Standards

Pollutant	Primary (health related)		Secondary (welfare related)	
	Averaging time	Concentration	Averaging time	Concentration
Total suspended particulates	Annual arithmetic mean**	50 μg/m^3	Annual arithmetic mean**	50 μg/m^3
	24-hour concentration***	150 μg/m^3	24-hour concentration***	150 μg/m^3
Sulfur dioxide (SO_2)	Annual mean**	80 μg/m^3 (0.03 ppm)		
	24-hour mean concentration***	365 μg/m^3 (0.14 ppm)		
			3-hour mean concentration***	1300 μg/m^3 (0.5 ppm)
Carbon monoxide (CO)	8-hour mean concentration***	10 μg/m^3 (9 ppm)		
	1-hour concentration***	40 μg/m^3 (35 ppm)		
Ozone (O_3)	1-hour concentration*	235 μg/m^3 (0.12 ppm)		
Nitrogen dioxide (NO_2)	Annual mean**	100 μg/m^3 (0.053 ppm)		
Lead (Pb)	3-month mean concentration**	1.5 μg/m^3		

Source: Clean Air Act (1990), * not to be exceeded more than once per year, average over 3 years; ** not to be exceeded; *** not to be exceeded more than once per year.

Table 5-3. Ambient air quality standards in the European Union

Pollutant	Standard limit value		Averaging period	Time target	Directives	Notes
Sulfur dioxide (SO_2)	Human health	350 μg/m³	1 hour		1999/30/EC	a
		125 μg/m³	24 hours			b
	Ecosystems	20 μg/m³	Calendar year and winter (1 October to 31 March)			
	Alert threshold	500μg/m³	Measured over three consecutive hours			c
Nitrogen dioxide (NO_2)	Human health	200 μg/m³	1 hour	2010	1999/30/EC	d
		40 μg/m³	24 hours	2010		
	Vegetation	30 μg/m³ (NO_x)	Calendar year			
	Alert threshold	400 μg/m³	Measured over three consecutive hours			c
Particulate matter (PM_{10})	Human health	50 μg/m³	24 hours	2010	1999/30/EC	e
		20 μg/m³	Calendar year	2010		
Lead (Pb)	Human health	0.5 μg/m³	Calendar year	2010	1999/30/EC	
Benzene (C_6H_6)	Human health	5 μg/m³	Calendar year	2010	2000/69/EC	
Carbon monoxide (CO)	Human health	10 μg/m³	Maximum daily 8-hour mean		2000/69/EC	
Ozone (O_3)	Human health	120 μg/m³	Maximum daily 8-hour mean	2010	2002/3/EC	f
	Vegetation	18,000 μg/m³	AOT40, calculated from 1 h values from May to July	2010		g
Arsenic (As)		6 ng/m³	Calendar year	2013	2004/107/EC	
Cadmium (Cd)		5 ng/m³		2013	2004/107/EC	
Nickel (Ni)		20 ng/m³		2013	2004/107/EC	
Benzo(a)pyrene ($C_{20}H_{12}$)		1 ng/m³		2013	2004/107/EC	

[a] Not to be exceeded more than 24 times a calendar year
[b] Not to be exceeded more than 3 times a calendar year
[c] At locations representative of air quality over at least 100 km² or an entire zone or agglomeration, whichever is the smaller
[d] Not to be exceeded more than 18 times a calendar year
[e] Not to be exceeded more than 7 times a calendar year
[f] Not to be exceeded on more than 25 days per calendar year averaged over three years
[g] Averaged over 5 years by 2010; AOT40 (expressed in [μg/m³]·hours) means the sum of the difference between hourly concentrations greater than 80 μg/m³ (= 40 parts per billion) and 80 μg/m³ over a given period using only the 1-hour values measured between 8:00 and 20:00 Central European Time each day

use of universal rules such as the Kantian imperative. If there is uncertainty on potential damages, the precautionary principle, to be discussed in part V, becomes an important element of environmental policy. This also holds for the principle of the sustainability of the human living space. Also in a pragmatic view, ethical norms relating to the environment can very well be internalized in individual preferences. Moreover, a pragmatic aspect is that we place institutional, most importantly constitutional constraints, on human behavior where it is judged that this is necessary. Such constraints represent a deviation from the individualistic principle; but they can be explained as the result of human experience with the task to reduce transaction costs and uphold a certain quality of the environment.

Also in a pragmatic view, ethical norms relating to the environment can very well be internalized in individual preferences. Moreover, a pragmatic aspect is that we place institutional, most importantly constitutional constraints, on human behavior where it is judged that this is necessary. Such constraints represent a deviation from the individualistic principle; but they can be explained as the result of human experience with the task to reduce transaction costs and uphold a certain quality of the environment.

An Example: Ambient Quality Standards

In practical environmental policy, sufficient information on prevented damage in monetary terms very often is not available. Standards for minimum quality of environmental media then are often established on an ad hoc basis taking into account information available in the different scientific disciplines on the impact of pollutants on health or on the natural environment. For instance, a minimum air quality may be specified for a metropolitan area, or quality standards for a river system or for groundwater may be set. It is reasonable to view these standards as fixed targets or as normative restrictions to other policy decisions. (Compare also the standard-price approach discussed in chapter 7.)

As an example of quality standards, Table 5-2 shows the national ambient air quality standards in the US for different pollutants. Fourteen primary standards are intended to protect health; secondary standards protect public welfare, as measured by effects of pollutant on vegetation, materials, and visibility. Table 5-3 summarizes ambient air quality standards in the European Union. The EU has adjusted its Directives and added new ones since 2000 on benzene, carbon monoxide, ozone, arsenic, cadmium, nickel, and benzopyrene.

[16] Compare US Clean Air Act (1990). On standards in Europe compare the directives of the European Commission, for instance 1999/30/EC.

6 Property-Rights Approach to the Environmental Problem

The public-goods approach to the environmental problem discussed in chapter 5 represents the basic argument for government intervention. The propertyrights idea can be considered as a counterposition. The property-rights approach suggests that if exclusive property rights are adequately defined, the public-good environmental quality can be transformed into a private good, and optimal environmental allocation will be reached. Government intervention, if necessary, is needed only in assigning environmental property titles. Property rights may also evolve in an evolutionary way in order to reduce transaction costs. With property rights adequately defined, the market will find the correct allocation. Both approaches agree that actually property rights are not adequately defined for the environment as a receptacle of waste. To change the environment as a common-property resource in its role as a receptacle of waste into a private good by assigning property rights for emissions is consistent with both approaches. Whereas the public-goods approach suggests that, because of the nature of public goods, property rights cannot be specified, the property-rights approach is more optimistic in this respect.

Property-Rights Approach

A property right can be defined as a set of rules specifying the use of scarce resources and goods (Furubotn and Pejovich 1972). The set of rules includes obligations and rights; the rules may be codified by law, or they may be institutionalized by other mechanisms such as social norms together with a pattern of sanctions. Property rights may be defined over a wide range of specific resource uses. Dales (1968) distinguishes four types of property rights:

First, *exclusive* property rights cover the right of disposal and the right to destroy the resource, notably the right of sale. But even this extensive form of ownership is controlled by a set of rules which protect other individuals or maintain economic values. For instance, a homeowner may not destroy his house. In cities we are not allowed to burn garbage on our property. If there is a mineral well near the lot you own, you may not be permitted to build a factory on your property. City zoning and criminal law are examples of restrictions on exclusive property rights.

Second, *status* or *functional ownership* refers to a set of rights accorded to some individuals, but not to others. In this case the right to use an object or to receive a service is very often not transferable. Examples of this type of right include licenses to drive a taxi or notarize documents, and, during the Middle Ages, the right of admission into a guild.

Third, *rights to use a public utility* (merit good such as a highway) or a public good (a national park) relate to a specific purpose.

Fourth, *common-property resources* represent de facto a nonproperty because nearly no exclusion is defined.[1]

Property rights may be transferable, or they may be limited to a specific person or status (such as functional ownership). Property rights may be defined with respect to the right to use the resource directly, or they may be defined such that use is allowed only in a very remote way. For instance, the right to vote in an election represents a property right in a general interpretation.

The property-rights approach represents a very interesting and powerful line of economic reasoning since it permits us to integrate economics with law and other social sciences. The property-rights approach can be interpreted as a contribution to the theory of institutions, where an *institution* is defined as a set of rules that specifies how things are done in a society. In terms of the property-rights approach, the basic question of economics can be posed: How are property rights to be defined so that the economic system generates "optimal" results? The word *optimal* may mean quite a few criteria, such as freedom of the individual and correct incentives to produce, to find new technologies, and to supply resources (for example, capital and labor). Also we may ask whether property rights can be defined in such a way that externalities are internalized.

Property Rights and Environmental Allocation

What are the implications of the property-rights approach for the environmental problem? As we have seen, historically property rights have not been defined for the use of the environment. Under such conditions, markets cannot fulfill the allocation function, and the resulting structure of production is distorted. For instance, if the fish of the oceans are treated as a common-property resource, this resource is overused. It has been pointed out that the growing desert of the Sahel region in Africa is due to the nonexistence of property rights. As a result of heavy fighting among migrating tribes over many years, a complex system of using the land as a common property has emerged that has not contained elements for the conservation of natural resources. Parts of northern Africa were the granary of the Roman Empire; after property rights were changed into a common-property pasture system by the Arabs in the sixth century, the conservation of the land degenerated.

[1] It is recommended to take a second look at some common properties. For instance, the village forest in the Swiss Alps may, at first glance, be interpreted as being a common property. A closer analysis often shows that there is a set of rules regulating its use. Thus, the forest may serve as a protection against avalanches, and withdrawal of wood is restricted.

This message of the property-rights approach is consistent with our analysis so far. The environment as a receptacle of waste, if used at a zero price, can be interpreted as a common-property resource. This implies, as is pointed out in chapter 2, an overuse of the environment and a distortion of sector structure in favor of the pollution-intensive sector. The property-rights approach requires that the property rights (or constraints) for using the environment should be more clearly defined, that is, that the character of common property be changed. The same implication follows from allocation analysis. The environment should no longer be used as a free good for receiving waste; rather, a scarcity price should be charged. One way of introducing a price and redefining property rights is to introduce an emission tax. Another way would be to auction pollution licenses. Finally, the government could specify maximum emissions per firm (permits) which would implicitly set a price on pollutants. In all these cases, the environment, as a receptacle of waste, would be transformed into a private resource with a positive price by defining a new set of rules.

There may be a second implication of the property-rights approach: Is it possible to define property rights in such a way that the public good "environmental quality" can also be transformed into a private good? Can we imagine such an exclusion technology whereby the characteristics of the public good "environmental quality" are changed? Exclusion technologies not only are determined by technical properties; they also depend on institutional arrangements, normative considerations, and the costs of exclusion. If exclusion is practicable, completely different policy implications result: The public goods approach to environmental problems motivates government intervention since the market does not provide public goods. The property-rights approach maintains that in many cases involving public goods, private property rights can be defined. Further, this approach asserts that more imagination is needed in order to find the correct institutional arrangements, and that government activity should be limited to cases where a definition of private property rights is not possible. In the following analysis, we proceed in two steps. First, we assume that property rights can be defined; then we ask how the attribution of property rights will affect environmental allocation. Later we look into the problem of whether property rights can be defined.

Coase Theorem

One of the basic results of the property-rights approach to environmental allocation has been proposed by Coase (1960). The Coase theorem states:

Let exclusive property titles to the environment be defined, and let them be transferable. Let there be no transaction costs. Let individuals maximize their utilities, and let them be nonaitruistic. Then a bargaining solution among different users of the environment will result in a Pareto-optimal allocation of the environment. The resulting allocation is independent of the initial distribution of property titles.

The Coase theorem can be illustrated with Fig. 5-2. For simplicity it is assumed that we consider two individuals, a polluter and a pollutee. We distinguish two cases.

Case 1. Assume the exclusive property right to the environment is given to the pollutee (consumer). The damage per unit of pollutants for the pollutee is indicated by curve OD. The damaged person will be willing to tolerate a certain degree of emissions if he is adequately compensated. The sufferer will agree to environmental impairment as long as the compensation per additional emission unit lies above his marginal-damage curve. The bargaining position of the sufferer thus moves along the marginal-damage curve OD in Fig. 5-2. On the other hand, the polluter is willing to offer compensation for the use of the environment as long as the compensation per unit of pollution is lower than his marginal abatement costs. Thus, the position of the polluter is determined by the curve S^0C of the marginal abatement costs. The result of this bargaining process is found at point W. Optimal environmental quality will be OS', and the required abated emissions will be S^0S'. The polluter will pay a compensation per unit of emission to the owner of the environment.

Case 2. Assume that the polluter owns the exclusive rigth to use the environment. In this case, the pollutee has to pay compensation so that the polluter avoids emissions. The willingness to pay of the sufferer is determined according to his marginal prevented damage; that is, his bargaining position is determined by curve OD. The polluter is willing to abate pollutants only if he receives a compensation greater than his marginal-cost curve of abatement S^0C. The solution is found again at point W. The same environmental quality results as was determined in case 1. Also the same quantity of emissions has to be abated.

The Coase theorem shows that optimal environmental allocation is independent of the initial distribution of property titles. This is a powerful result of the property-rights approach. The reader may see that Fig. 5-2 describes three different solutions to environmental allocation, namely, the optimization approach of chapter 4 (Pareto optimum), the benefit-cost approach, and the bargaining solution. All three approaches require the equality of marginal benefits (that is, marginal prevented damage) and marginal costs of abatement.

Whereas the allocation is independent of the definition of property rights, the distribution of income is not. Since income distribution may have a feedback on the marginal evaluation of environmental quality and on marginal costs (via demand, commodity, and factor prices), we must specify that, as an additional condition of the Coase theorem, income distribution does not affect these variables (at least not significantly), although we know that there is a feedback.

Coase Theorem and Transaction Costs

The impact of transaction costs on environmental allocation is shown in Fig. 6-1 (see p. 102). In Fig. 6-1 curve OD denotes marginal prevented damage, and curves S^0C indicates marginal abatement costs. Assume, now, that transaction costs arise and that they are carried by the party who tries to induce the owner of the environment to agree to a different use. Also assume for simplifying purposes that transaction costs can be defined per unit of emissions so that in this interpretation we can talk of marginal transaction costs. It is assumed that marginal transaction costs are constant.

Let us again distinguish between the two different cases of property titles.

Case 1. If the pollutee owns the environment, the polluter is willing to compensate the pollutee according to the polluter's marginal-cost curve CS^0. In this case, however, the polluter also has to carry the marginal transaction costs; the net transfer according to the pollutee who is endowed with the exclusive property right, therefore is given by the marginal abatement cost minus transaction costs. Relative to the situation without transaction costs, the compensation offered to the pollutee is reduced; the polluter's bargaining curve shifts downward from S^0C (in Fig. 6-1) to YT'' with the vertical distance between the curves representing the transaction costs per unit. Note that the curve shifts in a parallel fashion, that is marginal transaction costs are assumed to be constant.

With transaction costs, instead of point S', the new solution is at point V, so that more pollutants are abated (S^0V instead of S^0S'), and a higher environmental quality is obtained. This result is intuitively clear. Transaction costs raise the price of the right to pollute for the firm, so that the firm has an incentive to abate more.[2]

Case 2. If the polluter owns the environment, the pollutee's upper limit to compensate the polluter is the prevented damage (curve OD). But the pollutee will also have to carry the marginal costs of transactions so that he can only offer a compensation to the polluter consisting of the marginal prevented damage minus the transaction costs. In this case, the bargaining curve of the pollutee shifts downward from OD to ZT' This implies there is a reduced incentive to abate pollutants because the polluter receives a smaller transfer payment. Instead of S^0S' only S^0R pollutants will be abated; environmental quality will be lower.

As a result we have: When transaction costs exist, the environmental quality reached in a bargaining process varies with the institutional arrangement of property rights. The Coase theorem no longer holds.

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[2] Note that the curve YT'' in Fig. 6-1 displays the net benefit for the pollutee. If we were to draw the marginal cost curve for the firm (compare Fig. 7-1), transaction costs will shift the marginal cost schedule upward.

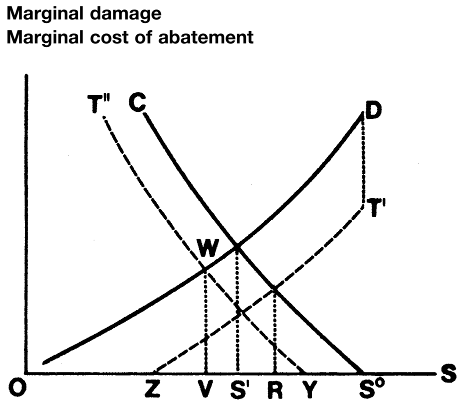

Fig. 6-1. Coase solution with transaction costs

In Fig. 6-1, constant marginal transaction costs have been assumed. If some fixed cost element in the bargaining process is involved, the determination of environmental quality will become more complicated. Fixed bargaining costs will have to be allocated to emissions abated in the bargaining process. It has also been pointed out that the pollutee may have higher transaction costs than the polluter. This may be due to the fact that the pollutees are many, or that they have to ensure participation of many in identifying the damages.

The Coase theorem has been criticized on many grounds, including the existence of differences in bargaining positions, relevance of transaction costs, insufficient analysis of the bargaining process, and equity considerations. The crucial factor, however, is that, in reality, we have more than one person in each bargaining party. Consequently, environmental quality is a public good for the consumer with nonrivalry in use, and the aforementioned free-rider problem arises. By assuming only one pollutee, the Coase theorem has assumed away the existence of public goods.

Can Property Rights Be Specified?

With respect to the definition of property rights, two levels of discussion have to be distinguished. Is exclusion technically feasible? And if so, is it normatively acceptable?

First, property rights for using the environment as a receptacle of waste can be defined so as to include even difficult cases such as the fluorocarbons from spray cans which affect the ozone layer. We can envision international treaties banning or reducing the production of fluorocarbons. In the case of regional or national environmental problems, property rights may also be established.

Second, property rights can be defined for using natural resources such as fish in the ocean. Via international negotiations, fishing permits may be introduced and allocated to different nations by means of auctions or political bargaining.

In the examples given above, however, even with property rights defined, there remains the public-goods problem. The ozone layer is a public good, and from a policy point of view we have to determine how much of the ozone layer ought to remain pollution-free. In solving this question, we meet the free-rider issue again; the willingness to pay of different individuals (or, more realistically, of nations) may not be truly revealed. The same problem arises in the case of oceans when the existence of a species such as whales is interpreted as being a public good to be enjoyed by all.

Whereas in the case of global or international environmental goods, such as the ozone layer or the Mediterranean Sea, the public good remains, more local types of environmental quality may lose their public-good character through exclusions. For instance, the cleanliness of a village in the German Odenwald may be a concern for the villagers, and this may be a group good. The village may develop social mechanisms in order to maintain this public good, and in this sense, property rights may be defined. Exclusion exists for national parks, for instance, when limits are placed on the number of overnight permits granted in order to reduce congestion. It is also conceivable to limit access by an entrance fee, that is, to exclude those not willing to pay a given price. In other instances, the price of land or houses denotes an implicit evaluation of a beautiful location and serves as a mechanism of exclusion and of revealing willingness to pay. Finally, we can envision a setting where the exclusive property right for the environment, such as the air quality of a region, is given to an individual (or a government agency), and the owner charges a price for providing this environmental quality. Those not willing to pay the price have to leave the region, while others willing to pay could move into the area. In all these examples, Samuelson's criterion that the public good is consumed in equal amounts by all no longer holds.

An advantage of the property-rights approach is that it has stimulated imagination with respect to the question of whether property rights can be specified. For instance, a hundred years ago people would not have believed that it would be possible to sell the airspace above one's house. This, however, happened in Manhattan as a result of new zoning laws. It is probable that today we are unable to conceive of all possible exclusion technologies which may eventually arise.

The definition of property rights has been a historical process. If we look at human development since Adam and Eve left paradise, the increasing scarcity of resources required the definition of property rights. When land was in ample supply, property titles for land were not necessary. When people competed for the scarce good "land" property titles became relevant. Similarly, water once was a free good, but today property titles for water are well accepted. The continuing endangerment of wildlife species or fish induces institutional arrangements for conserving these resources. And the increasing scarcity of energy or raw materials leads to property rights for energy and raw materials. Even in the case of the orchards and the bees, the prototype of examples of externalities discussed by Meade (1952), Cheung (1973) has shown that property rights have developed. It is interesting to note that some property rights have developed via private bargaining.

There are people who project this historical development into the future and who are confident that an adequate definition of property rights can be left to individual bargaining with only an initial stimulus provided by the government. I take the position that it is worthwhile to give additional thought to the question of how new property rights can be defined by economic policy.

In this endeavor, however, the problem arises as to whether technically possible exclusion mechanisms are morally acceptable. It is a value judgment that access to natural amenities such as a national park should be open to everyone under reasonable conditions. The idea of giving the exclusion right of the environment to an individual or a government agency and forcing those not willing to pay to leave the area may not easily be acceptable in a culture which has experienced the *cujus regio, ejus religio* principle.[3] Further, such an exclusion right would impede the citizens' freedom of movement. Thus, basic values of a society limit the range of possibilities in which property rights may be defined. However, from an allocation point of view exclusion is a necessary element in solving the environmental problem. We cannot exclude that values will change over time, so that the property-rights approach and the publicgoods approach to economic problems will remain interesting counterpositions in the future.

[3] This principle was used at the end of the Thirty Years' War in 1648 when the sovereign determined the religion of his subjects.

Part III
Environmental-Policy Instruments

7 Incidence of an Emission Tax

In part II we analyze optimal environmental allocation and suggest different approaches in order to determine the optimal environmental solution. Environmental allocation is placed into the context of static optimization models, the economics of public goods and the theory of property rights. In chapters 7, 8, 9 and 10, our interest shifts to environmental policy instruments. In chapter 7, we analyze how firms react to an emission tax, and what the overall incidence of an emission tax will be on environmental quality, emissions, the allocation of resources in production and abatement and sectoral structure. We thus analyze the incidence problem in detail for a specific instrument. In chapter 8, we survey the environmental policy instruments available looking at their relative advantages and disadvantages. In chapter 9, we analyze to what extent different policy instruments have to be used in different environmental problems. In chapter 10, we study some of the basic principles of environmental policy and major legislation.

The allocation models studied in chapters 3 and 4 suggest that a price tag should be attached to environmental use when the environment is treated as a receptacle for waste. How can this price be determined? In this chapter, we discuss what information is required to establish this price for environmental policy. From a practical point of view, prevented marginal damage can hardly be determined. Rather, a quality standard has to be set, and a standard-price approach has to be used. If a standard-price approach is followed, an important question is how polluters will react to a price tag on emissions. This is analyzed in some detail in chapter 7. One argument is that a monopolistic producer will shift the emission tax to the consumer. We show that, even in monopoly, an emission tax will represent an incentive to abate pollutants. Partial equilibrium analysis is not sufficient to provide a definitive answer with respect to the incidence of an emission tax. Therefore we construct a general equilibrium model in which the relative commodity price is determined endogenously. The assumptions of this general equilibrium model are specified, and the implications of the model are studied.

Standard-Price Approach

If we interpret the implications of the optimization model of chapter 4 as a guideline for economic policy, then our model indicates that in order to establish an emission tax, the following information is required: The policymaker needs information on the existing quantity of emissions, the level of abatement costs for alternative states of the environment, prevented damages and their evaluation, and diffusion between emissions and pollutants. In chapter 5 we discuss some of these information requirements in greater detail, such as specifying and evaluating prevented-damage and abatement costs. The evaluation of marginal damage is a condition that may not be given. Then the policymaker has to make an ad hoc decision on the level of environmental quality to be attained, and the target variable has to be determined in the political process. The economic dimension of the allocation problem is then reduced to the question of how the desired environmental quality can be achieved in an efficient way, that is, with minimal resource use of abatement.

This approach is illustrated in Fig. 7-1, where OS^0 represents the total quantity of emissions and S^0C denotes marginal abatement costs. Assume that a quality target OS' is fixed so that $S'S^0$ pollutants should be abated. Then an emission tax OT has to be set. This approach is the standard-price approach or the cap-and-trade approach. Note that Fig. 7-1 should be compared with other graphical illustrations in this book, such as Figs. 4-1, 5-2, and 6-1, all relating to the problem of how environmental quality to be determined.

The standard-price approach dispenses with the determination of environmental-policy benefits and presents instead a procedure that achieves an environmental standard with minimal abatement costs. Since the environmental standard is politically determined and not the result of an optimizing process, the desired environmental quality can be suboptimal. Only by chance will the standard be equivalent to the optimal environmental quality.

One way to implement a fixed quality target is for the government to levy an emission tax. Assume that the government does not have information on marginal abatement costs. Then the government could use a trial-and-error process and observe how the private sector would react to a given emission tax. If the firms would abate as many pollutants as were desired by the policymaker, the emission tax would not be changed. If the resulting environmental quality were

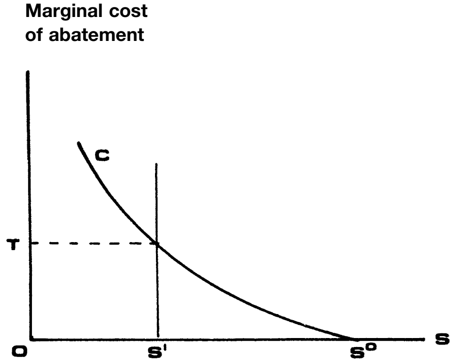

Fig. 7-1. Standard-price approach

too low, the emission tax would have to be raised. If environmental quality were higher than expected, then the emission tax would have to be reduced.

In the case of a standard-price or cap- and trade approach, a decisive question is: How will the private sector react to the emission tax? Will environmental quality be improved? Will the pollution-intensive sector be impeded? Will resources be transferred from production to abatement?

Reaction of Producers

In order to prepare the general-equilibrium analysis of the incidence of an emission tax, we first study how an economy adjusts to an emission tax if the product price is assumed as given. The decision of the individual producer can be explained with the help of Fig. 4-1a, where O_1S_1 denotes emissions and where S_1A represents marginal abatement costs. If the producer does not abate pollutants, he has to pay taxes. Tay payments are represented by the quadrangle with sides O_1T_1 and O_1S_1. If he abates pollutants, the producer's tax payment is reduced. The producer will abate pollutants as long as the marginal costs of abatement are lower than the emission tax. In Fig. 4-1a the producer will abate the quantity XS_1 of pollutants. If a lower emission tax than O_1T_1 is set, fewer pollutants will be abated. A higher emission tax implies that more pollutants will be abated.

Thus, the introduction of an emission tax represents an incentive to abate pollutants. The more important incentive function of an emission tax is to stimulate the search for a less pollution-intensive production technology and a more favorable abatement technology. Such technical progress would shift the cost curve of abatement to the left and reduce the total quantity of emissions. Unfortunately, this incentive for technical progress cannot be further considered in our static model.

The adaptation of the individual firm to an emission tax can be analyzed as follows. Assume that the firm maximizes profits and takes the price vector $(\tilde{p}_i, \tilde{r}, \tilde{z})$ as given. Then the problem is given by Eq. 4.8. Equation 4.9 indicates the profit-maximizing factor demand of the firm and implicitly defines demand functions for inputs in production R_i, and abatement R_i^r. These demand equations can explicitly be written as

$$R_i = \psi_i(\tilde{p}_i, \tilde{r}, \tilde{z})$$

$$R_i^r = \psi_i^\tau(\tilde{p}_i, \tilde{r}, \tilde{z})$$

Divide Eq. 4.9 by $\tilde{p}_2$; that is, choose commodity 2 as numéraire (with $p = \tilde{p}_1/\tilde{p}_2$, $r = \tilde{r}/\tilde{p}_2$, $z = \tilde{z}/\tilde{p}_2$). Then the system of Eq. 4.9 and the resource restriction 3.6 consist of five equations and contain the six variables r, p, R_i, R_i^r. The emission tax z is exogenously determined (by economic-policy decisions). For simplicity, assume that p is a constant; then we can find out how the economy reacts to the introduction of an emission tax. Total differentiation of Eqs. 3.6 and 4.9 yields

$$\begin{bmatrix} a_1 & 0 & 0 & 1 \\ 0 & a_2 & 0 & 1 \\ 0 & 0 & -zF_1^{r''} & 1 \\ zF_2^{r''} & zF_2^{r''} & zF_2^{r''} & 1 \end{bmatrix} \begin{bmatrix} dR_1 \\ dR_2 \\ dR_1^r \\ dr \end{bmatrix} = \begin{bmatrix} -H_1'F_1'dz \\ -H_2'F_2'dz \\ F_2^{r'}dz \\ F_2^{r'}dz \end{bmatrix} \tag{7.1}$$

with $a_i = zH_i''F_i'^2 - (\tilde{p}_i/\tilde{p}_2 - zH_i')F_i'' > 0$.

Equation 7.1 indicates the effects of a change in the emission tax on resource demand by the firm. Resources used determine output and abatement. From Appendix 7A we have

$$H_1'F_1' > H_2'F_2' \left\{ \frac{dR_1^r}{dz} > 0 \quad \text{and} \quad \frac{dR_1}{dz} < 0 \right. \tag{7.2}$$

Resource input in the pollution-intensive sector decreases, and resource use in the abatement activity of the pollution-intensive sector increases. Total resources used in sector 1, namely in production and abatement, will decrease. A definitive statement cannot be made with regard to resource use for production in the enviromentally favorable sector 2. There, resource for production use can increase or decrease. More resources can be used in the abatement activity of sector 2, so that a decrease of resource use for production in sector 2 cannot be excluded. Furthermore, we obtain the result

$$H_1'F_1' \gtreqless H_2'F_2' \left\{ \frac{\Sigma dR_i}{dz} < 0 \quad \text{and} \quad \frac{\Sigma dR_i^r}{dz} > 0 \right. \tag{7.3}$$

Resources are withdrawn from production and used in abatement. This indicates that the net emissions S decrease and that environmental quality improves. Furthermore, we know that the resource input decreases in the pollution-intensive sector.

In Fig. 3-3 this result can be shown graphically. Define an isoprice line for a given p and a varying z. Then the economy will move along that isoprice line from a point on the traditional transformation curve BC upward on the transformation space. The properties of this isoprice line are implicitly given by Eq. 4.9.

Emission Taxes in Monopoly

It is often argued that a monopolist will shift an emission tax to consumers and that consequently the incentive function of an emission tax will not apply in the case of a monopolistic producer. We want to analyze whether this argument is valid. The monopolistic producer has to take into account the same constraint as a competitive producer; however, the commodity price $\tilde{p}_i$ is not given. Instead the monopolistic producer is confronted with a demand function $\tilde{p}_i = \psi_i(Q_i)$. For simplicity, assume that the producer cannot influence the resource price and the emission tax. Then the profit-maximization problem of the monopolistic producer is given by

$$\Pi_i = \psi_i(Q_i)Q_i - \tilde{r}(R_i + R_i^r) - \tilde{z}S_i$$

subject to

$$\begin{aligned} &Q_i - F_i(R_i) \leqslant 0 \\ &H_i(Q_i) - S_i^p \leqslant 0 \\ &S_i^r - F_i^r(R_i^r) \leqslant 0 \\ &-S_i + S_i^p - S_i^r \leqslant 0 \end{aligned} \tag{7.4}$$

The reader should compare Eq. 7.4 with Eq. 4.8. The implications of the maximization problem for the monopolist are

$$Q_i \frac{\partial \psi_i}{\partial Q_i} + \psi_i(Q_i) = \frac{r}{F_i'} + \tilde{z}H_i' \tag{7.5a}$$

$$\tilde{z} = \frac{\tilde{r}}{F_i^{r\prime}} \tag{7.5b}$$

Equation 7.5 a specifies that the monopolist will equate marginal revenue with marginal costs of production (including environmental costs). Because of the declining marginal revenue, the monopolist will produce a lower output compared to a firm in perfect competition. Consequently, he/she will produce fewer pollutants. In this sense, the monopolist is the environmentalist's friend.

Equation 7.5 b specifies that the monopolist will abate pollutants as long as marginal abatement costs are lower than the emission tax. Assume O_1S_1 in Fig. 4-1 a is total emissions of the monopolist, and let S_1A denote the curve of marginal abatement costs. Then the monopolist will abate S_1X pollutants. Equation 7.5 b is identical to the case of perfect competition. Therefore, the emission tax acts as an environmental incentive even under monopolistic conditions.

Additional aspects of a monopoly and oligopolies are analyzed in Rauscher (2005) and Requate (2006).

General Equilibrium Approach

In the analysis of the incidence of an emission tax in perfect competition, we have assumed a constant relative commodity price p. In reality, we can expect that the relative price will change and that the change in relative price will affect sector structure and the allocation of resources. Consequently, we have to give up the assumption of a constant relative price. The relative price has to be determined endogenously in the model. Our frame of reference is the twosector model specified in chapter 3. We introduce the following additional assumptions.[1]

Commodity demand is given by

$$C_i = C_i(p, Y) \tag{7.6}$$

where $p = \tilde{p}_i / \tilde{p}_2$ is the relative price.

Income Y is defined from the production side. There are no savings. In order to close the model, we assume that the government spends the tax receipts by redistributing them to the households. Consequently, disposable income of the households is identical to net national income at market prices and is defined as

$$Y = pQ_1 + Q_2 \tag{7.7}$$

Observe that Y includes transfers not explicitly shown and that p is the consumers' price, not the producers' price. If Y were defined with respect to the producers' price p^*, emission taxes (and transfers) would appear explicitly on the right side of Eq. 7.7.

Commodity markets must be in equilibrium, so that

$$Q_i = C_i \tag{7.8}$$

Additionally, we require Eqs. 3.1 through 3.6 and Eq. 4.9. This system of equations contains the seventeen variables S_i^p, S_i, S_i^r, Q_i, R_i, R_i^r, Q_i^p, p, Y, and r and eighteen equations. The definition of Y in Eq. 7.7 states that the total demand is equal to income, so that in a two-sector model the equilibrium condition for one of the product markets is redundant (Walras' law) and should be omitted. By substitution the system can be simplified to

$$F_1(R_1) = C_1(p, pF_1(R_1) + F_2(R_2)) \tag{7.9a}$$

$$r = zF_i^{r\prime}(R_i^r) \tag{7.9b}$$

$$r = (p - zH_1')F_1'(R_1) \tag{7.9c}$$

$$r = (1 - zH_2')F_2'(R_2) \tag{7.9d}$$

$$\bar{R} = R_1 + R_2 + R_1^r + R_2^r \tag{7.9e}$$

The structure of the model is shown in Fig. 7.2. The model contains three subsystems: the political system, the resource market, and the commodity

[1] On this approach compare Siebert (1978-a).

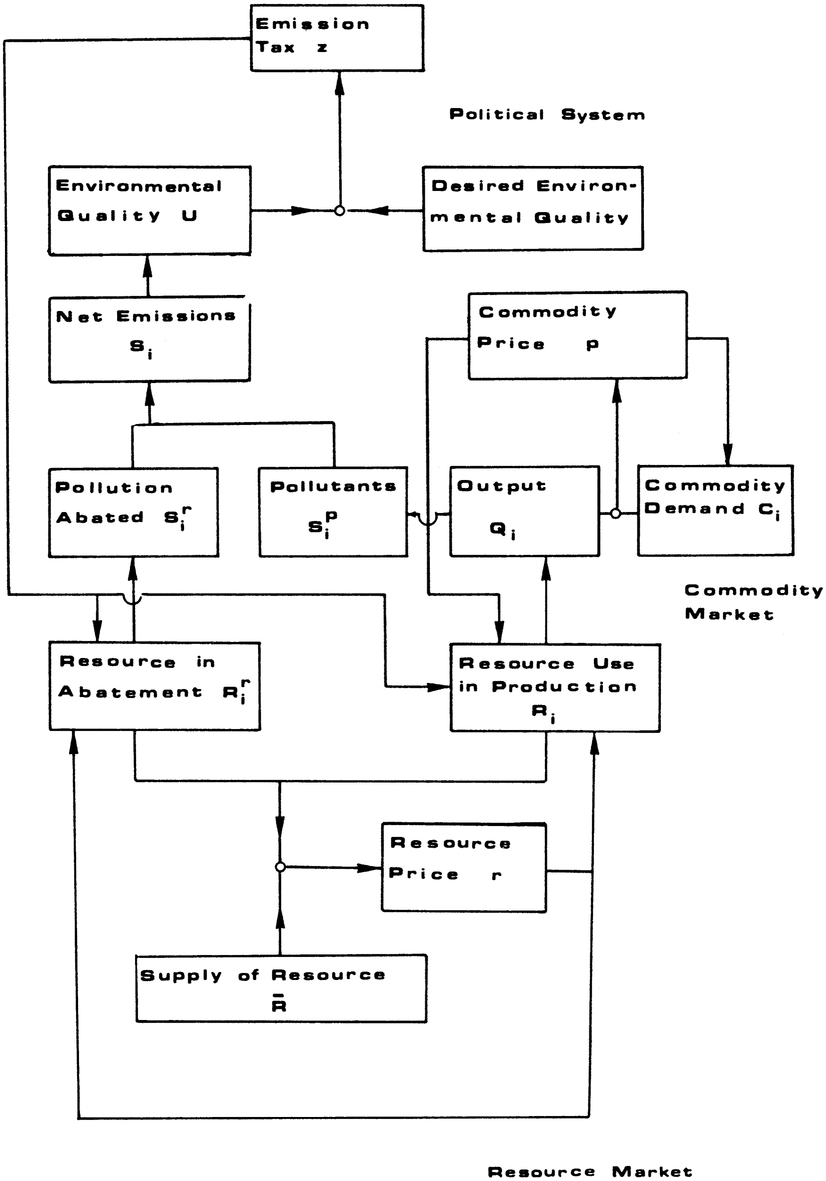

Fig. 7-2. Structure of general equilibrium model

market. In the political system, the existing and the desired environmental qualities are compared, and an emission tax is established. The emission tax influences the resource demand for abatement and for production. Resource demand and resource supply determine the resource price; in turn, the resource price affects resource demand. Resource use in production is determined by the emission tax, by the resource price, and by the commodity price p. The commodity price p is a result of demand and supply in the commodity market. Resource use in production determines gross emissions; resource use in abatement accounts for abated pollutants. Gross emissions minus abated emissions define net emissions, which, in turn, influence environmental quality.

Allocation in a General Equilibrium Model

We want to analyze how an emission tax will affect environmental quality, sectoral output, and the allocation of resources. Total differentiation and substitution of 7.9e into 7.9a to 7.9d yields

$$\begin{bmatrix} a_1 & 0 & 0 & 1 & -F'_1 \\ 0 & a_2 & 0 & 1 & 0 \\ 0 & 0 & -zF_1^{r''} & 1 & 0 \\ zF_2^{r''} & zF_2^{r''} & zF_2^{r''} & 1 & 0 \\ b_1F'_1 & -C'_{1Y}F'_2 & 0 & 0 & -b_2 \end{bmatrix} \begin{bmatrix} dR_1 \\ dR_2 \\ dR_1^r \\ dr \\ dp \end{bmatrix} = \begin{bmatrix} -H'_1F'_1dz \\ -H'_2F'_2dz \\ F_1^{r'}dz \\ F_2^{r'}dz \\ 0 \end{bmatrix} \tag{7.10}$$

The coefficients are defined as follows:

$$b_1 = 1 - C'_{1Y}p = C'_{2Y} \tag{7.11a}$$

$$b_2 = C'_{1p} + C'_{1Y}F_1 < 0 \tag{7.11b}$$

Note that $b_2 < 0$ follows from Slutsky's rule. Let $C'_{1Y_{\text{comp}}}$ denote the pure substitution effect. We have

$$C'_{1p} = C'_{1p_{\text{comp}}} - C'_{1Y}C_1$$

or

$$C'_{1p_{\text{comp}}} = C'_{1p} + C'_{1Y}F_1(R_1) = b_2 < 0$$

since the pure substitution effect is always negative. Note that Eq. 7.10 contains Eq. 7.1 as a subsystem in the first four rows and first four columns. From Appendix 7B we have the following results:

$$\Delta > 0 \quad \begin{cases} C'_{2Y} \geqslant 0 \\ C'_{1Y}F'_2 + C'_{2Y}F'_1 \geqslant 0 \end{cases} \tag{7.12a}$$

$$\frac{dR_1^r}{dz} > 0 \quad C'_{1Y}F'_2 + C'_{2Y}F'_1 \geqslant 0 \tag{7.12b}$$

Assuming 7.12a is given, we have

$$\frac{\Sigma dR_i}{dz} < 0 \tag{7.13a}$$

$$\frac{dR_1}{dz} < 0 \begin{cases} C'_{1Y} \geqslant 0 \\ H'_1F'_1 > H'_2F'_2 \end{cases} \tag{7.13b}$$

$$\frac{dp}{dz} > 0 \begin{cases} H'_1F'_1 > H'_2F'_2 \\ a_2C'_{2Y}F'^2_1 p \geqslant a_1C'_{1Y}F'^2_2 \end{cases} \tag{7.13c}$$

$$\frac{dY}{dz} < 0 \begin{cases} H'_1F'_1 > H'_2F'_2 \\ -\eta_{1p} > \alpha > 1 \text{ with } \alpha = \dfrac{1}{1 - F'_2/pF'_1} \end{cases} \tag{7.13d}$$

where $-\eta_{1p}$ is the price elasticity of demand for the pollution-intensively produced commodity.

Allocation

Assume that both commodities are not inferior, so that their marginal propensities to consume ($C'_{iY} \geq 0$) are nonnegative. Then the determinant Δ is positive, that is, $\Delta > 0$. Assume that sector 1 is the pollution-intensive sector, that is, $H'_1F'_1, > H'_2F'_2$. Then we can conclude that resource use in the pollution-intensive sector will decline. Resource use in each abatement activity will increase; resource use in production (ΣR_i) will be reduced.

Environmental policy will shift the sector structure of the economy in favor of the abatement activities while production will be negatively affected. We can establish that production in the pollution-intensive sector will decline. In the less pollution-intensive sector 2, resource use may increase or decrease. The model allows for both cases. Thus, in one case, sector 1 and sector 2 lose resources to the abatement activity, whereas in the other case sector 1 loses resources to sector 2 and the abatement activity.

Environmental Quality

Given our assumptions, emissions will decline and environmental quality will improve. This follows from $\Sigma dR_i/dz < 0$ and $\Sigma dR_i^r/dz > 0$.

Relative Price

Equation 7.13c specifies the conditions under which the relative price of the pollution-intensive commodity will rise. We have two sufficient conditions.

1. $C'_{2Y} \geq pC'_{1Y}$. Under the conditions specified below, national income will decline as a consequence of environmental policy. Then $C'_{2Y} \geq pC'_{1Y}$ guarantees that demand for the pollution-intensive commodity 1 is reduced less than demand for commodity 2. This difference in the income effect of the two commodities ensures that the relative price of the pollution-intensive commodity must rise.
2. For $a_2 \geq a_1$, $| dR_1/dr | > | dR_2/dr |$ specifies[2] that (for given p and z) sector 1 is more sensitive to changes in resource price than sector 2; we may also say that sector 1 is more dependent on resource R. This condition can be interpreted as a rudimentary form of a factor-intensity condition in a one-factor model. We can expect that this condition unfolds into a set of factor-intensity conditions in a multifactor model. As a result, we know that the relative price of the pollution-intensive commodity will rise if the marginal propensity to consume this commodity is lower than the less pollution-intensive commodity and if the pollution-intensive sector depends heavily on resource R.

Sufficient conditions for a rise in the relative price can partly substitute each other. Assume that sector 1 is very pollution-intensive. Then the relative price of commodity 1 may rise even if it has a high income elasticity of demand (and if it loses demand quantities with a decline in income). Or, for identical pollution intensities of both sectors, the relative price will rise if sector 1 is characterized by a sufficiently smaller income elasticity of demand. If this is so, then sector 1 loses a smaller quantity of demand. This requires a higher adjustment in relative price. Finally, assume that sector 2 is very dependent on resource R. Then p can rise anyway, when sector 1 is sufficiently more pollution-intensive or when sector 1 has a sufficiently lower income elasticity.

National Income

Environmental policy affects net national product at market prices Y in two ways. First, resource use in production will decrease, so that for a given price p national income will fall (withdrawal effect). Second, the pollution-intensive commodity has to be revalued since the market price must include the social costs of production. The revaluation effect runs counter to the withdrawal effect.

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[2] Differentiate the factor-demand conditions 7.9 for given p and z with respect to r:

$$\frac{dR_i}{dr} = \frac{1}{(p_i/p_2 - zH'_i)F''_i - zH''_i F'^2_i} = -\frac{1}{a_1}$$

and

$$\left|\frac{dR_1}{dz}\right| > \left|\frac{dR_2}{dz}\right| \Leftrightarrow a_2 > a_1$$

National income will fall if the withdrawal effect outweighs the revaluation effect. This is the case if the price elasticity of demand for the pollution-intensive commodity η_{1p} is sufficiently large, that is, $-\eta_{1p} > \alpha > 1$. A high price elasticity of demand for commodity 1 ensures that the pollution-intensive sector will lose large quantities of demand so that the revaluation effect will not be too high.

From the definition of α, we have an interesting interrelation between demand conditions and the condition of emission intensity.

First, assume that sector 1 is strongly pollution-intensive so that α is close to unity[3]. Then the price elasticity does not have to be too high if the withdrawal effect is to be strong. A high pollution intensity in sector 1 means that production costs will rise sharply in sector 1, relative prices will rise, and sector 1 will lose quantities of demand even if the price elasticity of demand is not too high.

Second, if sector 1 is relatively nonpollution-intensive compared to sector 2, then α is higher than unity, and the demand for the pollution-intensive commodity must be very price-elastic in order for demand quantities to decline. In other words, in condition 7.13c a high price elasticity of demand for the pollution-intensive commodity may be substituted by a strong pollution intensity of production in sector 1.

Summary the Allocation Effects

Under the specified conditions, the introduction of an emission tax will reduce emissions and will improve environmental quality. Resource use and output of the pollution-intensive sector will decline, and resource use in abatement will increase. The relative price of the pollution-intensive commodity will rise, so that demand for it will decline. The emission tax drives a wedge between the market price and the producers' price. Finally, under the specified conditions, national income will fall. This means that there is a tradeoff between environmental quality and the maximization of national income. The effects of environmental policy are depicted in Fig. 7-3. The effects can also be analyzed through use of the transformation space in Fig. 3-3. Given an initial situation on the transformation curve BC, the economy moves upward on the transformation space. Whereas environmental quality is improved, national income decreases. Also, the relative price changes, sector structure, and the allocation of resources are affected.

[3] Note that $pF'_1 = r + zH'_1F'_1$ and $F'_2 = r + zH'_2F'_2$, so that $H'_1F'_1 > H'_2F'_2$ implies that $F'_2/(pF'_1) < 1$.

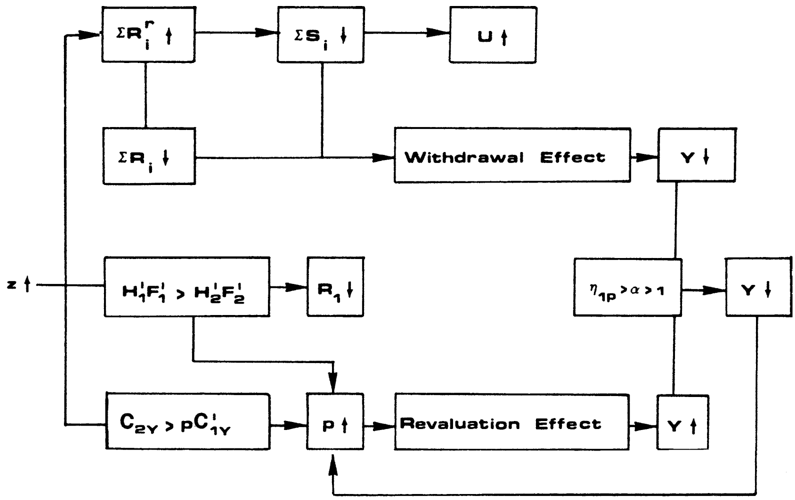

Fig. 7-3. Main effects of an emission tax

Pollution Intensities, Factor Intensities, and Allocation Effects

The model presented can be made more realistic if additional adaptations of the economic system are considered.

Two Factors of Production

In the analysis so far, we have assumed only one factor of production. If we assume that different types of inputs are used in production and in abatement, we can expect additional conditions for the allocation incidence of an emission tax. Besides the pollution intensity of the two sectors, we also have to distinguish between the capital intensity and the labor intensity of production and pollution abatement. Assume, for instance, that the pollution-intensive sector 1 is also characterized by a labor-intensive production and by a capital-intensive abatement. Let the nonpollution-intensive sector 2 be characterized by capital-intensive production. Then environmental policy will increase the production costs in sector 1 and, *ceteris paribus*, reduce output there. The reduction of output means a decrease in factor demand. Since sector 1 is labor-intensive, its demand for labor will fall relatively more than for capital. Because of the capital intensity of abatement in sector 1, the demand for capital will rise. Under such conditions, the relative demand of sector 1 for capital increases. If, at the same time, sector 2 is capital-intensive and if the nonpollution-intensive sector 2 increases output, then the demand for capital rises. Since the relative demand for capital in the economy rises, the wage-interest

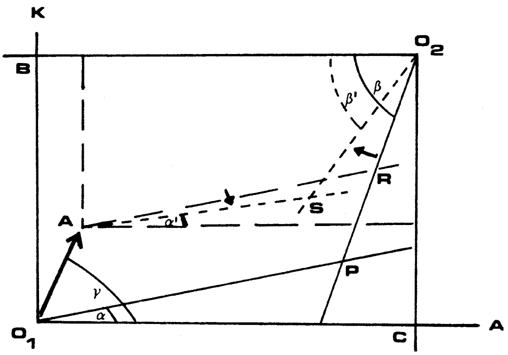

Fig. 7-4. Allocation effects in a two-factor model

ratio falls. This implies that in all activities capital will be substituted by labor; and the capital intensity will rise. This case is illustrated in Fig. 7-4.

Assume a given factor endowment with capital endowment O_1B and labor endowment O_1C. Let K denote capital and A labor. The capital intensity of sector 1, $k_1 = K_1/A_1$, is given by $tg\alpha$. The capital intensity of sector 2 is given by $tg\beta$. In the initial situation, no environmental policy is undertaken. Point P denotes the initial allocation of resources in the Edgeworth box with O_1P denoting output of sector 1 and O_2P indicating output of sector 2.

Assume, now, that environmental policy is undertaken. Assume that a given level of abatement is specified and that O_1A indicates the withdrawal effect of resources through abatement. Note that the capital intensity of abatement is given by $tg\gamma$. It is assumed in Fig. 7-4 that abatement is capital-intensive, relative to production in sector 1. The withdrawal effect of resources from production means that the Edgeworth box becomes smaller. With given relative factor prices, the allocation shifts from P to R. For a given relative factor price, output in both sectors is reduced. In our example, however, we have an additional effect, the reduction of the wage-interest ratio. This means that the capital intensity will fall from $tg\alpha$ to $tg\alpha'$ in sector 1 and from $tg\beta$ to $tg\beta'$ in sector 2. This implies a substitution of capital by labor. Substitution of capital by labor affects a movement from point R to point S. Sector 2 adjusts to the new relative price and makes itself less dependent on capital.

In Fig. 7-4, sector 1 is assumed to be relatively pollution-intensive and labor-intensive in production and capital-intensive in abatement. It is apparent that the allocation effects depend on the factor intensities in production and abatement. There may be cases in which the result is not clear in one direction, for instance, if sector 1 is capital-intensive in production and abatement. Also, demand conditions have an impact on the output level, on the relative commodity price, and on the relative factor price. For a more thorough analysis of the allocation incidence in a two-factor world, compare Siebert et al. (1980).

Other Extensions

The allocation model discussed in this chapter could be extended in several ways in order to make it more realistic. Thus, we have assumed a given production, emission, and abatement technology. It seems to be realistic to expect that an emission tax will represent an incentive to find less pollution-intensive production technologies and to improve abatement. Furthermore, we should take into consideration that an industry consists of different types of firms. Firms differ in size, age, and technological capabilities. Consequently, an emission tax will also have an impact on industrial structure. The allocation incidence may also be different if we compare a one-product with a multiproduct firm. Moreover, the allocation incidence will vary with the type of policy instruments used. Assume for instance, that instead of an emission tax, a permit system with emission norms is used as a policy instrument. Then the emissions of an individual polluter (or a specific source of emissions) are limited by a restraint

$$S_i \leqslant \bar{S}_i$$

so that the maximization problem of the firm stated in Eq. 4.8 has an additional restraint, but there are no tax payments for emissions. We can specify the profit-maximizing supply and factor demand of the individual firm; we can also determine how the individual firm and the economy as a whole reacts to a change in emission standards.

Overshooting of the Emission Tax

Our incidence analysis is undertaken in a static framework. It was mentioned earlier that in setting the emission tax the government may follow a trial-and-error procedure. Once an emission tax is introduced, the government observes the resulting environment quality; if it diverges from the target, the emission tax will be adjusted.

This trial-and-error procedure may give rise to oscillations in the emission tax if the adjustments in pollution abatement take time. For instance, capital formation in the abatement activity may be a reason for a lagged response. It may take time to build pollution capital. Then a given emission tax may only yield the desired result with a time lag. If environmental policy reacts too quickly, the emission tax will "overshoot", and a misallocation of resources will result.

Is there a Double Dividend of Emission Taxes?

It has been proposed that under a set of conditions environmental taxes will not only improve environmental quality but will have positive side effects on economic welfare such as efficiency gains or will be associated with more favorable conditions for other policy targets such as employment (Oates 1991,

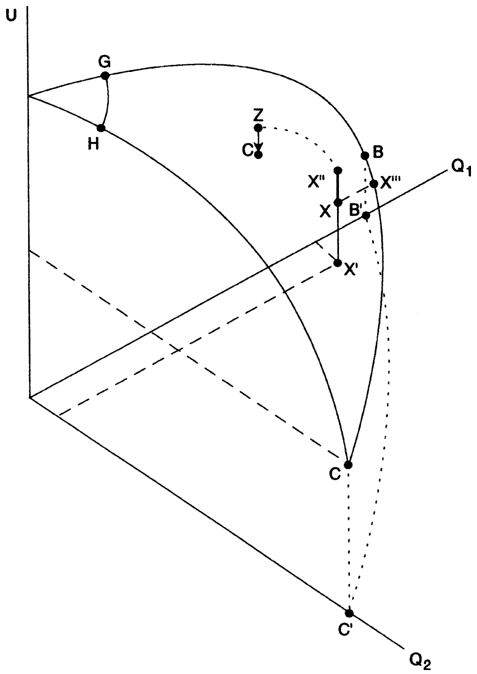

Fig. 7-5. Double dividend of an emission tax

Pearce 1991). The basic idea is that an economy may be in a second or third best (nth best) situation and that environmental policy will move the economy to a first best or second best (n-i best) situation. In analyzing the impact of an environmental policy instrument, a general equilibrium analysis has to be applied so that all repercussions (including second and third round effects) are taken into consideration.

Take a situation as in Fig. 7-5 with production in the economy initially at point X. Production at point X is distorted for two reasons:

i) Relative to preferences, too much of the environmentally damaged good is produced. Environmental quality is not optimal.

ii) Due to other distortions and inefficiencies, production is not at the surface of the production possibility frontier, but inside.

If an appropriate policy instrument (or a combination of policy instruments) can be found, the economy moves from point X to the optimal point C corresponding to the preferences (including preferences for the environment) and at the same time it moves from inside the production space to its surface. In that sense there is a double dividend.

It is, however, possible that the environmental policy instrument moves production further away from the surface of the production possibility frontier.

In this case, the policy instrument may raise environmental quality, but it also exacerbates initial distortions. This may be due to the fact that in the presence of non-environmental distortions, e.g. taxes, imperfect competition, and that due to missing markets for environmental quality, environmental taxes might aggravate preexisting distortions under quite general conditions (Bovenberg and de Mooij 1994; Fullerton 1997). Then, policy makers are faced with uncertainty (Goulder 1995) and have no guarantee that environmental taxes are welfare increasing. Under these conditions a double dividend may not exist.

In the public and academic debate on the double dividend, a specific condition is often attached, namely that the introduction of environmental taxes represents a revenue-neutral change in the tax mix with government expenditure remaining constant.

Whereas in principle a double dividend is possible, its existence depends on a number of conditions, either of theoretical or practical relevance:

First, the extent and type of the initial distortion is relevant. If there is no distortion initially, there can be no double dividend. It can be expected that under appropriate ceteris paribus conditions the probability of a double dividend is greater the larger the initial distortion is.

Second, it matters whether environmental policy will effectively reduce the initial distortion. It cannot be excluded that environmental policy will introduce additional distortions. Then, environmental policy will have additional opportunity costs in moving production further inside the production space. The double dividend then turns into a negative dividend.

Third, the actual discussion on ecological tax reform is linked to substituting taxes on labor (including contributions to social insurance) by environmental taxes (Bovenberg and de Mooij 1994). Here the question arises whether the tax base will erode (Scholz 1996). Emission taxes can be avoided by abatement technology and other reactions. Consequently, the correct environmental taxes do not provide a secure tax base (Sachverständigenrat 1994, p. 212). This erosion effect might make it impossible for the government to cut other distortionary taxes sufficiently due to budget constraints. In this case the government is not able to compensate economic subjects through tax cuts sufficiently. As a result, the distortions of the tax system increase (Bovenberg and de Mooij 1994).

Fourth, in a context where product taxes (on dirty goods) instead of emission taxes are applied, the elasticity of substitution between the dirty and the clean good must be limited in order to restrain the erosion effect of the tax base (Scholz 1996).

In Figure 7-6, the implications of a double dividend are illustrated. Consider first the usual case of environmental policy without any positive side effects of environmental policy. In that case, the emission tax t is set in such a way that prevented marginal damage (MD) and marginal costs of abatement (MC) equate at point S. The economy has costs of abatement c (triangle EIS), but it has gross benefits c + b (ISTE), so that b (EST) represents net benefits of abatement. Tax revenue is OZSI. Introduce now in a second step additional distortions given in the initial situation. If the tax revenue from emission taxes is now used to reduce distortions in the tax system, the cost curve of abatement

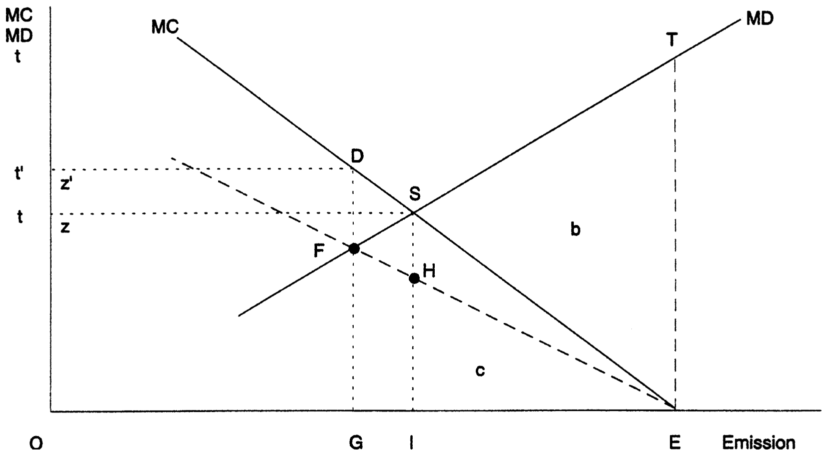

Fig. 7-6. Positive side effects

rotates downwards (ray EHF), because net costs of environmental policy are reduced by these additional benefits. Relative to the initial situation S, the additional benefit due to the side effects is given by the triangle EFS. Note that the optimal environmental tax is now set higher at t'.

If the side effects exacerbate the initial distortion, the relevant marginal cost curve rotates upwards. Then there is an additional loss.

Most empirical studies come to the conclusion that the side effect is negative, i.e., that initial distortions of the tax system are increased (Goulder 1995, p. 171). A positive side effect is found only when the elasticity of capital supply and capital demand is high. This indicates that the marginal excess burden of capital taxation is relatively high in the initial situation.

The discussion on the double dividend should not be interpreted in a misleading way. The double dividend should not be misunderstood to mean that improving the environment is not associated with opportunity costs of foregone production. Improving environmental quality means moving up the transformation space in Fig. 7-5. This implies that private production is reduced. Thus, there are opportunity costs.

Partly, the discussion on the double dividend is reminiscent of the question whether environmental policy will improve employment or not (chapter 5). Whereas it is accepted that new jobs are added in environmental-friendly sectors, when environmental policy is undertaken, old jobs are destroyed in environmental-intensive activities. If technical knowledge does not change, full employment can only be obtained if on average each individual (i.e., also each worker) bears the opportunity costs of lower production, that is lower real income, while enjoying an improved environmental quality.

Instruments in a Second-Best Setting

The effectiveness of environmental policy instruments becomes a more complex issue under conditions of second best when for instance distortionary taxes exist in a situation before environmental policy instruments are introduced (Goulder et al. 1999). With preexisting distortionary taxes (for instance on factors) the costs of pollution abatement are raised. This suggests that environmental policy instruments can obtain better results when distortionary taxes do not exist. This is in line with the philosophy of a double dividend: One policy instrument can achieve two goals.

Appendix 7A: Reaction of the Individual Firm

The determinant of Eq. 7.1 is given by

$$A = -a_1 a_2 z(F_1^{r''} F_2^{r''}) + z^2 F_1^{r''} F_2^{r''}(a_1 + a_2) > 0 \tag{7 A.1}$$

Define

$$A_1 = a_2 p F_1'(F_1^{r''} + F_2^{r''}) - z^2 F_1^{r''} F_2^{r''}(H_1' F_1' - H_2' F_2') \tag{7 A.2}$$

$$A_2 = a_1 F_2'(F_1^{r''} + F_2^{r''}) + z^2 F_1^{r''} F_2^{r''}(H_1' F_1' - H_2' F_2') \tag{7 A.3}$$

The solutions are

$$\frac{dR_1}{dz} = \frac{A_1}{A} \tag{7 A.4}$$

$$\frac{dR_2}{dz} = \frac{A_2}{A} \tag{7 A.5}$$

$$\frac{dR_1^r}{dz} = \frac{A_3}{A} = -\frac{F_2^{r''}}{A}(a_1 F_2' + a_2 p F_1') \tag{7 A.6}$$

Appendix 7 B: General Equilibrium Model

We have

$$\Delta = -b_2 C - a_2 C_{2Y}' F_1'^2 z(F_1^{r''} + F_2^{r''}) + z^2 F_1' F_1^{r''} F_2^{r''} (C_{1Y}' F_2' + C_{2Y}' F_1') \ . \tag{7 B.1}$$

Define

$$\Delta_1 = -b_2 Z_1 + F_1' F_2'^2 C_{1Y}' (F_1^{r''} + F_2^{r''}) \tag{7 B.2}$$

$$\frac{dR_1}{dz} = \frac{\Delta_1}{\Delta} \tag{7 B.3}$$

$$\frac{dR_2}{dz} = \frac{\Delta_2}{\Delta} \tag{7 B.4}$$

$$\Delta_2 = b_2 Z_2 + F_1'^2 F_2' C_{2Y}' (F_1^{r''} + F_2^{r''}) \tag{7 B.5}$$

$$\frac{dR_1^r}{dz} = \frac{\Delta_3}{\Delta} \tag{7 B.6}$$

$$\Delta_3 = -b_2 Z_3 - F_1' F_2' F_2^{r''} (C_{1Y}' F_2' + C_{2Y}' F_1') \tag{7 B.7}$$

$$\frac{dp}{dz} = \frac{\Delta_5}{\Delta} \tag{7 B.8}$$

$$\Delta_5 = -C_{1Y}' F_2' Z_2 - C_{2Y}' F_1' Z_1 \tag{7 B.9}$$

$$\frac{dY}{dz} = \frac{1}{C}[(F_1^{r''} + F_2^{r''}) F_1'^2 F_2'^2 + (b_2 - Q_1 C_{1Y}') \cdot (-pF_1' Z_1 + F_2' Z_2) - F_1' Z_1 Q_1] \tag{7 B.10}$$

8 Policy Instruments

In this chapter, we study how the basic ideas of allocation theory can be implemented and which policy instruments can be used to reach a desired environmental quality. The set of available policy instruments is reviewed. The basic message of allocation theory for practical policy is that environmental scarcity must be taken into consideration in individual decisionmaking. We study in some detail the regulatory approach, emission taxes, and pollution licenses. Furthermore, water associations are considered. They represent an interesting institutional arrangement by which the costs of environmental-quality targets can be attributed via cost sharing to individual polluters. Finally, we look at liability rules.

Transforming Quality Targets into Individual Behavior

The problem of using environmental-policy instruments consists of finding institutional arrangements or policies such that a given target of environmental quality is reached by the individual decisions of the polluters. How can we transform a quality target for an environmental medium into the emission (and abatement) behavior of individual agents? This problem can be studied from different angles of the doctrine of economic thought which are all more or less related to each other.

From the point of view of the property rights literature, finding the appropriate institutional arrangements is just a manifestation of devising new property rights that allow to express environmental scarcity. Compare our discussion in chapter 6.

A related concept can be found in the problem of *Ordnungspolitik* stressed by the German Freiburg School in the 1930s. The question here was to devise a frame of reference or a set of rules (Ordnungsrahmen) for an economy defining the operating space for private activities.

From the discipline of economic policy in the European tradition, the problem of environmental policy instruments can be interpreted as a transformation problem, namely the question of choosing the best policy instrument in order to reach the set target. Another approach is the principal-agent paradigm.

The Principal-Agent Problem

According to the principal-agent literature (Fama 1980; Grossman and Hart 1983; Xepapadeas 1991), the policy maker as a principal chooses the desired environmental quality and attempts to influence the decisions of the individual agents, namely the households and the firms, in such a way that the target is eventually reached. The problem then is to devise an institutional arrangement and to define incentives which make sure that the behavior of the individual agents contributes to the overall target. This is the issue of incentive compatibility.

The principal has to start from the premise that the agents will maximize their utility or their profits. Thus, if we consider production, the environmental policy maker as a principal has to take into account the optimality conditions of firms as a restraint of its maximization behavior. Equations 4.9a and 4.9b denote these constraints for the principal. These equations specify the optimal factor demand for production and the optimal factor demand for abatement. Equation 4.9b describes how a profit maximizing firm adjusts to a different level of the effluent charge z. It defines the reaction function of the firm to the emission tax. Graphically, this reaction function of the individual firms or of industries is given by Figs. 4-1a and 4-1b. The task for the principal is to set emission taxes such that they are equal to marginal damage prevented and to marginal abatement costs (see Fig. 4-1c). Thus, in an environment without uncertainty and with perfect information, the allocation solution presented in chapters 4 and 5 will be the result of the principal-agent problem. In this approach, the principal maximizes the net benefit of environmental quality under the restraint of the reaction function of the firm.[1] This maximization problem subject to a constraint may be interpreted as a one-shot maximization problem, it may also be interpreted as a two-stage problem where first the reaction function of the firm is determined and then the optimal emission tax is set.

In addition to the reaction function of the agent derived from his optimality condition an overall condition has to be taken into account which guarantees a positive profit at the given location or which shows a negative profit for another location. The negative value of another location is derived from relocation costs. Apparently, environmental policy can increase the costs of production at a given location in such a way that it is worthwhile for the firm to relocate. In evaluating the exit option, expectations of the agent on environmental policy play an important role. Assume for instance, that the agent has uncertainty on the question how environmental policy at his present location and at potential alternative locations will develop in the future. If he expects that environmental

[1] The target function of the principal can be expressed in several ways. One possible formula of the target function is that the principal minimizes environmental damage $D(S)$ minus his receipts from pollution zS so that his target function is Min $D(S)$—$-zS$. Alternatively, he can be supposed to be maximizing his receipts from the emission tax minus environmental damages that is Max $zS–D(S)$. The emission tax z in his target function links directly to the optimality condition of the agents.

policy will become more strict at home than at the other location, there is a negative option value for waiting with the relocation decision and the negative value of the outside option decreases. If the agent expects a stricter environmental policy at his present location, but is rather confident that with new technical knowledge he will be able to adjust to this environmental policy, the option value of staying at the old location may not be negative.

In the real world, things are more complicated, and here the specific advantage of the principal-agent approach comes to bear. One aspect is that the government does not have all the information which the agents have, for instance on abatement technology. Information between principal and agent is distributed asymmetrically. Consequently, the principal cannot perfectly determine the reaction function of the agent. Another aspect is that uncertainty on the impact of emissions as well as on effects of abatement activities on environmental quality exists. Thus, environmental quality will depend on a stochastic process defining different states of nature.

The polluter has the option not to provide all relevant information faithfully. It is in the interest of the polluter to play down his or her role in causing environmental pollution. Monitoring emissions therefore will play a crucial role in any incentive scheme.

But measuring emissions is not the only problem. Uncertainty on the amount of environmental damages and uncertainty on abatement technology, for instance on progress in abatement technologies, make institutional setting more complicated. It can be assumed that the polluter has better information on abatement costs; the principal as a representative of the pollutees is supposed to have better information on marginal damage. The situation therefore boils down to finding such institutional arrangements of risk allocation that will avoid distorting information and fending off the approach of using the environment as a recipient for waste free of charge. The institutional arrangement must be fit to transform stochastic into deterministic variables. If the polluter has the option to behave strategically, environmental quality targets are not correctly signalled to the subsystems of an economy.

Available Policy Instruments

We may distinguish among the following instruments:

1. The policymaker attempts to influence the targets of private subjects in such a way that the social impact of private decisions is considered more carefully; that is, the government tries to change the orientation of households and producers.
2. Pollution abatement is interpreted as a government activity; it is financed by general taxation.
3. The government pays subsidies in order to induce abatement activities or reduce pollution. The subsidies are financed by general taxes.

4. A regulatory approach is followed in which the government specifies the maximum amount of emissions per firm or per equipment (emission norms, permits). When a quality target is violated in an environmental medium, no new permit can be issued.
5. A price per unit of emission is charged (emission tax, effluent charge) with the intent to induce abatement or less pollution-intensive technologies.
6. By fixing the quality target, the policymaker determines the tolerable total quantity of all emissions, that is, the sum of emission rights for an environmental medium. These emission rights are given to those who are willing to pay the highest price; that is, they are auctioned among competing users in an artificial market for pollution licenses.
7. Associations for specific environmental media are formed that either determine the quality target themselves or implement the quality target which is specified by the policymaker. The role of these associations is to distribute the costs of achieving a desired environmental quality to the polluters; the attribution of costs should be undertaken in such a way that incentives for abatement are created.

Criteria for Evaluating Instruments

The choice of a specific environmental policy must take into account a set of criteria.

Ecological Incidence. Environmental-policy instruments are chosen in order to transform a given environmental quality into a desired condition. Therefore an important criterion is that the instrument induce abatement and improve environmental quality.

Economic Efficiency. Environmental policy results in significant costs. These consist of resource costs and target losses to macroeconomic policy objectives. Since these costs mean forgone opportunities, the level of costs will determine the scope of environmental policy. Consequently, a given quality target has to be reached with minimum costs.

Information. For the practical application of environmental-policy instruments, it is crucial to know what kind of information is presupposed by the various instruments, to what extent this information can be technically provided, and how much the required information will cost.

Management Costs. Information costs represent only one aspect of the performance costs of an environmental-policy instrument. Management expenses also include the costs of implementation and control of the instruments as well as the possible costs in the form of forgone flexibility (bureaucratization).

Practicability. Environmental policy instruments cannot be regarded in an organization, institutional, or political vacuum. The choice of instruments can also be influenced by how much opposition is generated among various parties such as policy administrators or special-interest groups.

Time Lag of Incidence. This criterion refers to the question of how long it will take until an environmental-policy measure improves environmental quality.

Transition Problem. The introduction of environmental-policy instruments represents an abrupt change in the frame of reference of individual behavior. Consequently, we must ask how an environmental-policy instrument will resolve the resulting transition problem.

Seriousness of the Problem. The estimation of the environmental problem is a further determinant of the instruments to be chosen. If the environmental problem is regarded as being very serious for a certain environmental medium, then the status of ecological efficiency possibly acquires a higher rank in comparison to economic efficiency. If the environmental situation is estimated such that after consideration of the transition costs, a short-term solution is not imperative, then the criterion of economic efficiency becomes more important.

Type of Problem. Since instruments have the function of transforming a given situation into a desired one, the choice of the instruments is unavoidably dependent on the type of problem. Therefore special importance should be placed on whether the same instruments can be used for different environmental media and whether – even if only one environmental medium is considered – different environmental problems can be distinguished for an environmental medium. These differences require that various instruments be employed.

In theory (compare chapter 4), the choice of a policy instrument is determined by maximizing welfare. In practice, the choice of a policy instrument is a multidimensional problem. There are many criteria to be considered. One can expect that a specific environmental-policy measure can be favorable with regard to some criteria and unfavorable concerning others.

Moral Suasion

Moral suasion is an attempt to influence the preferences and the targets of private economic subjects including managers in such a way that the social consequences of private decisions are considered. It includes a change of ethical norms with respect to nature and ecological problems. This approach may bring about results, but since the economic success of an enterprise is the central element of a free-market system, we cannot rely on firms to consider the social effects of their economic decisions. Rather, it should be the task of the economist to change the frame of reference (the institutional conditions) of private economic decisions in such a way that social costs are internalized.

Government Financing and Subsidies

One approach to the environmental problem would be that the government has to undertake pollution abatement and that abatement activities have to be financed by general taxation. If we take into account environmental conditions, this approach is not very feasible for air pollution. Also, it seems to be a good principle to prevent emissions from entering environmental media instead of abating them after they have entered the media. An increase in government activity along these lines would reduce the role of the private sector and increase that of the public sector. This would negatively affect the decentralization of the economy. Therefore, we have to look for other policy instruments. The role of the government in this respect is to redefine the conditions of individual activity in such a way that private costs do not differ substantially fromt the social costs of individual activities. The provision of a public good does not mandate that the good is actually produced or even financed by the government. Adequate institutional arrangements may be all what is called for in order to ensure the provision of public goods.

Subsidies are proposed in a number of forms in environmental policy. Quite a few objections can be raised against subsidies. They have to be financed by general taxes, and in most industrialized countries subsidies already account for a large part of the budget. Also, whereas most subsidies are motivated by social policies such as health care or agriculture, the environmental problem is an allocation question. The main objection to subsidies, however, is that subsidies stimulate the pollution-intensive commodity. They take over a part of the environmental damage. Because of this subsidization, the enterprise does not need to introduce these costs into its price. Therefore, the price of the pollution-intensive commodity is too low in comparison to commodities being produced favorably to the environment. The price structure as an allocation guideline does not change as is desired. In comparison to a desired optimal situation, excessive quantities of pollution-intensive commodities should be limited. The subsidy systematically distorts the economic price mechanism and causes a false allocation of resources, as discussed in chapter 2. In the following considerations, we focus on the regulatory approach, emission taxes, and pollution licenses.

Regulatory Approach

The regulatory approach seeks to reach a given quality target for an environmental system by regulating individual behavior. The typical instruments are pollution permits, that is, allowances to emit a specific quantity of a pollutant into an environmental system. Permits are issued until the quality target has been reached; then no further permits are issued.[2]

[2] This procedure is for instance followed in the German Bundesimmissionsschutzgesetz.

Regulations can take different forms according to what they specify. The usual permit is a property right to emit a maximum quantity of pollutants. Other types of regulations are obligations to reduce a given amount of pollutants, in absolute or in relative quantities. Still other examples of this approach include regulations which stipulate the state of technology to be applied in abatement or production or which monitor the type of input to be used. Product norms may define the quantity of pollutants which are contained in goods (for example, DDT in agricultural products) or which emerge through the use of commodities (noise emitted through the use of commodities such as a car). Production quantities may be limited, or production of a specific product may be prohibited. Finally, the location of firms may be forbidden in a specific area.

The regulatory approach has been widely used in environmental policy. Thus, water- and air-quality management in the United States is based on a permit system. Air-quality policy is also based on a permit system in Europe and Japan.

The advantage of the regulatory approach is seen in its ecological incidence. If the quality target is properly set and if private emitters do not violate the relevant laws, then the quality target will be reached. This argument makes the regulatory approach very attractive to environmentalists. It is claimed that the regulatory approach may have advantages in the case of environmental risks (see chapter 17). Unfortunately, the regulatory approach has severe shortcomings.

Inefficiency

The regulatory approach requires a set of emission rules that apply to all emitters of a specific pollutant. The policymaker planes the economic subsystems by using a general approach, and thus he is not able to take into account particular differences. Therefore, the regulatory approach is inefficient. As an example, consider an obligation to reduce a given amount of pollutants by x percent. We neglect the announcement effect which would clearly indicate that the level of pollutants should not be reduced before the instrument is applied (in fact, more pollution should be produced now so that one will be faced with only a relatively small reduction later). In Fig. 8-1, the marginal abatement costs of two firms are shown. Firm 1 has relatively unfavorable abatement costs, whereas firm 2 can abate at lower costs. If both firms have to reduce their emissions by one-third, firm 1 will abate S_1A with relatively high abatement costs, and firm 2 will abate S_2B with relatively low abatement costs. Abatement is inefficient in the sense that firm 2 can abate BC of the pollutants at a lower cost than firm 1 can abate AD. An emission tax OT shows the efficient solution.

The inefficiency argument implies that resources are wasted. Thus, the opportunity costs are too high. Sinc the costs of environmental policy will have an effect on the target level, inefficient abatement implies less environmental quality. Therefore, the regulatory approach reduces the chances for an effective environmental policy.

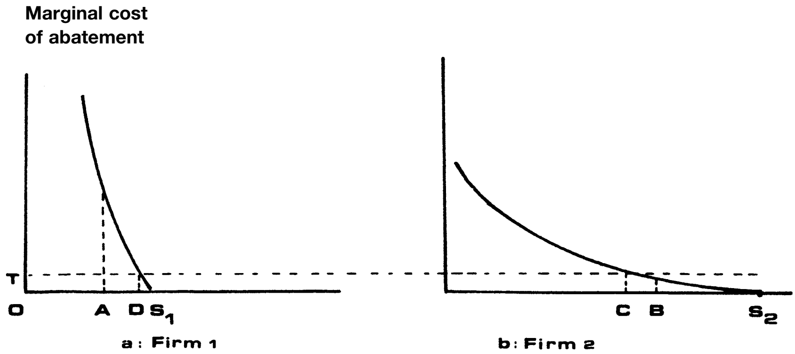

Fig. 8-1. Effect of an instruction to reduce emissions

Bureaucracy

Government agencies have to issue permits specifying the allowable quantity of emissions for specific equipment within the firm. For instance, in the North Rhine-Westphalia region of West Germany, air-quality policy attempts to regulate each stationary source of emission (Dreyhaupt 1979). We may call this approach the "individual stack policy" where the government regulates each individual facility. In North Rhine-Westphalia, about 10,000 permits are said to exist relating to air quality, not counting the de-facto permits of older facilities. In 1986, 40,000 facilities in West Germany were licensed according to the law of air-quality management. According to Mills (1978, p. 186), 46,000 permits were issued in the United States for water pollution as a result of new legislation in the period from 1972 to 1976. We may doubt whether a government agency has all the necessary information to make a proper assessment in such matters. We may also note that such decisions may create an atmosphere in which government interference with individual decisions, even in other fields, becomes a widely-accepted practice. Incidentally, in West Germany the time required to obtain pollution permits for traditional facilities averages about three years.

No Scarcity Price

The regulatory approach allocates pollution permits on a first come, first served basis. This is not a very feasible allocation mechanism. Some companies receive permits at a zero price; others are charged at a price of infinity (that is, this factor of production is not available). The approach does not solve the common-property problem of environmental use.

Grandfather Clause

As a practical problem, the permit approach can only be used for new facilities; old installations have a de-facto permit either through an explicit grandfather clause or through the impossibility of reworking existing permits.

Newcomers and Dynamic Firms

The regulatory approach views the economy as being a static entity. When no more permits can be issued, newcomers cannot begin to produce or to locate in a region and dynamic firms cannot expand. Permits represent a protection for existing firms; permits tend to perpetuate the given structure of existing firms. Spatial structure is likely to become encrusted. This consequence of the regulatory approach is not only to the disadvantage of business; it also negatively affects labor. New firms may not be able to locate in a region although they may provide interesting and improved employment opportunities.

State of Technology

Permits very often require that the producers use the existing state of technology. For instance, the air-quality law in West Germany stipulates such a condition. This condition has a very interesting implication: The government will try to prove that new technologies are possible whereas the entrepreneur will use his energy to show that these new technologies are not feasible or not economical. We have feedback on the economic system. Whereas in a market economy it is the role of firms to find new technologies, given our scenario, firms will relinquish this function to the government.

Productivity Slowdown

The grandfather clause is an incentive to use old technology. The state of the art requirement encrusts the given technology and does not introduce a decentralized incentive to improve abatement and production technology. And the closing off of a region to a newcomer reduces mobility and implies efficiency losses. All these phenomena reduce productivity or result in a slowdown of productivity increase.

The Role of Courts

In most countries, government decisions can be made subject to checks by the courts. For instance, in West Germany the residents or the firms affected by a permit may go to the administrative courts on at least two levels. There are examples where a court has withdrawn a permit already granted by local administration only to have a higher court reverse this decision after a year or two. Regulations give a greater role to the courts in the allocation process. But, excluding exceptional cases, allocation of resources cannot be undertaken by the courts.

These disadvantages of the regulatory approach to the environmental problem suggest that the economist has to search for other solutions by which scarcity is correctly expressed. Therefore we consider the possibility of introducing prices accounting for environmental scarcity.

Voluntary Agreements

Instead of governmental regulation, Germany has used voluntary agreements with industry to reduce environmental degradation, especially in the areas of air pollution and waste management. In about a hundred agreements negotiated between government and industry associations, abatement targets (mostly for air quality management) and implementation-oriented specific measures (in waste management) have been specified (Kirkpatrick, Klepper, and Price 2001: 20). These agreements represent self-obligations of industry: they are not legally binding, but the government can threaten to make them so if no compliance is observed. In the new area of environmental policy, the advantage of these agreements – a form of Germany's method of consensus – is that a voluntary informal solution can be found instead of a mandatory one. Such an approach may be appropriate for uncharted waters, when the policy maker has scarce information on what can be done. However, the approach also has its shortcomings. The agreements reflect the interest of the incumbents, which of course do not want to alter their position any more than necessary. Thus, the environmental effectiveness of agreement is limited. Moreover, industry associations have no power to enforce environmental solutions. Finally, industry associations may represent a form of a cartel; they may use environmental agreements to enhance the monopolistic position of their member firms.

Emission Taxes

The intent of an emission tax is to introduce a scarcity price for emissions. In chapters 4 and 5 we discuss the level at which the emission tax has to be set. In the following analysis, we examine some problems connected with emission taxes.[3]

[3] A more detailed analysis can be found in Siebert (1976c). Also compare Siebert (1982b).

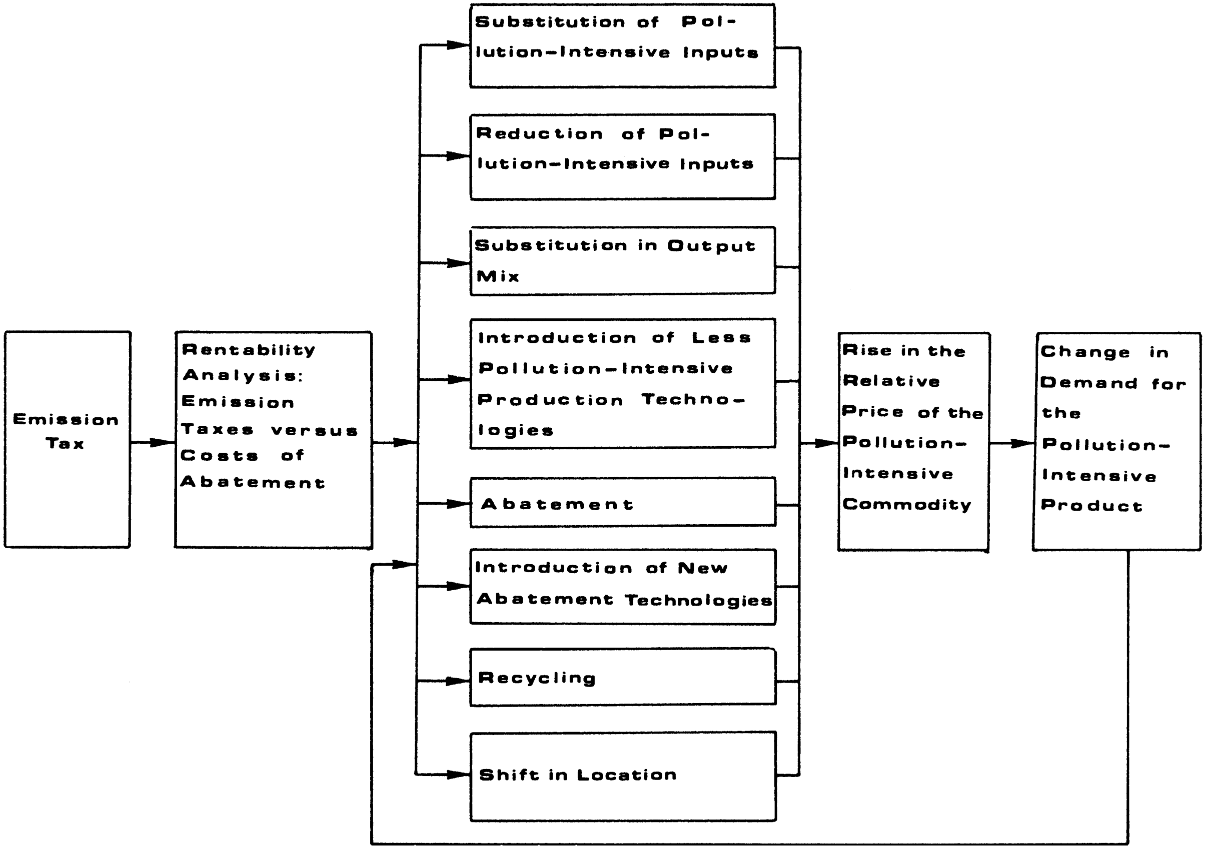

Fig. 8-2. Reactions to an emission tax

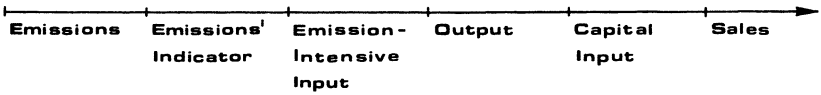

Fig. 8-3. Tax bases of an emission tax

Reaction of Firms

In chapter 7 we analyze the reaction of firms to an emission tax. In this inquiry, we undertook a static analysis. Now, for policy considerations, we have to take into account all possible reactions to an emission tax. One of the most crucial reactions is the inducement of improved abatement technologies. Each individual firm has a definite incentive to improve its abatement technology and to reduce tax payments. Figure 8-2 summarizes possible reactions. It shows that the decisive adaptations have to take place within the firms. After these adjustments have been implemented, relative prices will change and demand will be adjusted accordingly. The advantage of prices for using the environment as a waste sink is that responses of firms include adjustments that are not known yet when the price is introduced. Most importantly, scarcity prices will stimulate new technological solutions.

Tax Base

The correct tax base for an emission tax or an effluent charge is the quantity of emissions, measured in pounds or tons. In practical policy, we can expect that information problems will arise and that alternative tax bases need to be used. Figure 8-3 shows some tax bases.

Assume that the quantities of emissions are not known and that we have to use proxies for emissions. Then we can show that we will not obtain the desired reactions. Let an emissions indicator such as SO_2 be considered representative of all air pollutants such as CO, NO_2, and particulates. Then, by taxing the indicator, we stimulate abatement of SO_2 but not of the other pollutants. It is quite possible that in the process of abating SO_2, other emissions will be increased. A similar indicator problem arises in water-quality management if emissions are calculated in units equivalent to the wastes per inhabitant. In all these cases, the indicator should be constantly revised.

If pollution-intensive inputs are taxed, we introduce an incentive to economize on these inputs; however, this target may nevertheless be reached with more emissions. Firms may use less inputs, but they may switch to more pollution-intensive inputs. In this context, the problem of the second-best solution arises. Assume that we want to differentiate the tax according to a reasonable criterion such as levying a higher tax rate in winter than in summer. If the tax base is the SO_2 content of heating oil, firms will not pollute less in winter but will buy more oil in summer and store it. Or assume that you want to use a higher tax on heating oil in a metropolitan center than in the countryside because of more severe pollution in the metropolitan center. Then we will have interregional trade, and in order to prevent it, we will have to create an artificial monopoly for the oil supplier in town.

If the tax is based on pollution-intensive outputs rather than emissions, we only obtain a change in relative price and in demand. There is no response originating in the abatement and production activities. Tax bases such as capital input or sales will distort reactions even further. Finally, if a rather general tax is levied, such as a "Waldpfennig" on transactions in general, the emissiont tax loses all its incentive functions.

Measuring Emissions

It is an important question of environmental policy whether emissions can be measured within reasonable cost parameters. Note that this question also arises for the regulatory approach because, with permits, quantities of emissions are specified. According to older estimates, investment costs for a monitoring station are on average between 200,000 – 300,000 euro. Assuming a life time of ten years, this implies capital costs of 20,000 – 30,000 euro per year. Operating costs amount to a range of 5 to 10 percent of investment costs, i.e., 10,000 – 30,000 euro per year. Total costs for the monitoring station per year thus are in the range of 30,000 – 60,000 euro per year. As a rule each monitoring station measures four pollutants, in most cases CO, SO_2, NO_X, and an additional pollutant varying with local conditions.

Emission technology has improved considerably since the 1970s. Self-reporting is the usual practice in monitoring emissions in the case of permits. Self-reporting, backed up by occasional checks and by measurement of the ambient environmental quality, seems to be a practical approach to the measurement problem.

This, however, may not be a feasible way for emissions from households and other small and medium sized sources, whose contribution, to the total emission quantity and thus their reduction and substitution potential may be considerable. This is for instance the case with CO_2- and NO_X-emissions from household heating systems and automobiles. Here measuring costs can be insurmountably high. But there is some hope that new measuring technology may lead to a sharp decrease in costs.

Interaction of Pollutants

When pollutants are diffused or when interactions such as synergisms occur, the link between emissions and environmental quality variables seems to be destroyed. This problem, however, relates not only to emission taxes but also to regulation and pollution licenses. We must require that the political process which establishes the quality target also determines the total quantity of tolerable emissions. This would imply that diffusion processes would have to be taken into consideration. The point is that quality targets are given and appropriate emission taxes must be found so that these targets will be reached.

In setting these taxes, one must consider that an emission tax for pollutant A may lead to more pollutants of another type B. For instance, the tax for emission A may induce a new production technology with more emissions of type B. Or an emission tax may reduce emissions into the environmental medium a, but increase emissions into medium ß. Therefore, a correct vector for emission taxes has to be found so that the appropriate relative prices for different types of emissions are set. It is a tricky problem to find the correct relative price among pollutants.

Emission Tax as a Political Price

Who will set the emission tax? One procedure is for the legislature to specify a nationally uniform tax rate. This approach has been followed in Germany's effluent charge for waste water. This law defines a unit of emission based on an emission indicator. The fee started with DM 12 (1.1.1981), then slowly was increased to DM 50 in 1991 (DM 18 in 1982, DM 24 in 1983, DM 30 in 1984, DM 40 in 1986). In 1993, the rate was raised to DM 60, and to DM 70 in 1997. The law was passed in 1978 with the established tax rates being valid until 1986. It now stands at 35.79 euro. Allowing for the time required to prepare and enact such laws, prices have to be fixed which will apply for a period of ten years or more.

Another procedure would be for the legislature to define the quality targets for different environmental media with respect to the most important pollutants and to transfer the right to determine emission taxes to an independent government agency. The agency would be limited by the quality targets; its role would be to set prices and adjust them in such a way that the targets would be reached.

Such an institutional setting would be consisting with nationally uniform environmental-policy instruments; it could also be applied to a regionalization of environmental policy. For instance, the national legislature may define national quality targets while the regional authorities may set additional regional emission taxes (compare chapter 14).

Pollution Licenses

Pollution licenses limit the total quantity of tolerable emissions for an environmental medium in a political process. Then these emission rights are sold to those wanting to use the environment as a waste receptor. The limited quantity of emission rights is allocated through an artificial market where polluters represent demand and the government determines supply. This is the standard price approach or the cap-and-trade approach.

Pollution rights must be transferable. If a firm learns that it can abate emissions at lower costs, it must be able to sell its pollution rights to another polluter. Or if a firm wants to locate in a different area, it must be able to acquire pollution rights by inducing abatement in an existing firm. The transferability of pollution rights brings about flexibility in the allocation of the limited quantity of tolerable emissions.

This approach is beneficial because it combines the advantages of the regulatory approach with the advantages of emission taxes. By specifying the total quantity of tolerable emissions, environmental quality is clearly determined; there is no uncertainty with respect to the total quantity of emissions. In addition, a price is charged for using the environment as a waste receptor. Another advantage compared to emission taxes is that the government does not have to worry about the correct price relationship among different types of pollutants. The government only has to set the quality targets for different environmental systems. Once these quality targets are specified, the market will find the correct relative prices. Substitution will take place until a set of "equilibrium prices" for pollution rights is found such that demand equals supply of pollution rights.

Pollution rights may be easily used in the case of regionalized environmental policy (compare chapter 14). Assume that environmental policy sets different quality targets for regional media, for instance, in order to protect a specific area of natural beauty. Then fewer pollution rights would be supplied for this area. The price for a pollution right would be higher; consequently, either more abatement would take place, or fewer pollution-intensive sectors would locate in that region.

The following problems are connected with pollution rights: How can a market for pollution rights be created? How are regions delineated where pollution rights can be traded? Should rights be auctioned off? How long should rights last?

Market Creation

It is crucial for the efficient functioning of pollution licenses that a genuine market for trade in such licenses develops and an equilibrium market price is established. This requires that pollution licenses are clearly defined and property rights guaranteed, that the potential market volume is large enough, and that search and transaction costs are kept to a minimum. If these conditions are not fulfilled, the polluters' benefits from abatement are uncertain and potentially beneficial investments and trading in pollution licenses remain below the optimum level.

Delineation of Regions

Whereas emission taxes may be used nationwide, pollution rights presuppose regional delineation of environmental media since the total quantity of rights must be defined for a specific area. Pollution rights are easier to implement for a river system than for an air system. As we show in chapter 14, interregional diffusion is an important issue in this context. If we have two regions, each with different environmental scarcity, it may be profitable to locate firms in those places of the less polluted area that are very close to the polluted region (economies of agglomeration). Thus, pollution rights may induce a spatial structure that is not desired. It may be necessary to introduce zoning in this case. Zoning may also be required if we have concentrations of pollution within an environmental region. However, zoning implies that pollution rights may have to be differentiated according to zones within an environmental region. This could restrict transferability and thus would take away some of the advantages of this proposal. Pollution licenses are advantageous for environmental media with a wider spatial dimension, where regional delineation does not matter. Global environmental media are an example.

Here a predicament becomes obvious, which narrows the scope of the possible application of tradeable pollution licenses. In the case of substances that are harmful in high enough concentrations and form dangerous local immission hot spots, e.g., dioxin, the quantity of local emissions must be restricted accurately.

Issuing only locally valid pollution licenses would, in principle, solve this problem. But the development of an efficient market for such local licenses is highly unlikely and possible trades would more or less have the character of simple compensations for which the existence of a genuine market price for licenses is not necessary. On the contrary, the case of pollutants for which a regionalization of license markets is not required (CO_2) is ideal for the application of tradeable pollution licenses under the aspect of the creation of an efficient license market.

However, in this case an exact quantitative restriction of total emissions in the license area is ecologically usually also not required. For instance, in the case of CO_2 emissions, nature offers some flexibility with respect to permissible emission quantities and hence an emission tax may be similarly successful in reducing overall emissions.

An alternative approach to regionalization may be the combination of command and control instruments with pollution licenses. In such a setting pollution licenses may only be used to justify emissions which remain below the level of the emission quantity permitted for each individual source. This maximum emission level would be fixed in such a way that any damage to the population and the local environment will be safely avoided (Gefahrenabwehrprinzip). For a further reduction of emissions as a preventive measure (Vorsorgeprinzip) pollution licenses may then be used without any regionalization and segmentation of markets being necessary. The more weight is put on preventive considerations the less binding the command and control regulations will be and subsequently abatement becomes more and more efficient (Heister and Michaelis 1991).

Complementary in Demand

A given facility requires a set of pollution rights where pollutants normally are in a constant relation to one another. If such technical conditions are given, the transferability of pollution rights may be reduced. It is interesting to note, however, that some substitution already takes place within a firm if a firm has more than one facility.

Auctioneering the Pollution Rights

One procedure for allocating pollution rights is to auction them. For instance, all pollution rights would be sold each year on a specific date in public bidding. An argument against this procedure is that firms are confronted with the risk of not receiving a pollution right, an event which could endanger their existence. From an allocation point of view, the auction merely serves to sell and buy a factor of production. Althoug firms may get used to this procedure, we have to recognize that a firm usually has some certainty on the availability of factors of production such as capital, land, and labor. If the market process withdraws factors of production from a firm, it normally does so over a period of time. However, in the case of an auction for pollution rights for each year, we may have abrupt changes. This discontinuity in the availability of a factor of production may be prevented if bidding is done at more than one date, or if pollution rights last longer than the interval between bidding dates. It does not occur when a continuous supply of pollution licenses is available in the market.

Pollution Rights According to Initial Pollution

The problem of uncertainty may be prevented by giving pollution rights to the existing polluters. In this case, one could ask them to reduce pollution by a given percentage over a number of years and grant them the right to emit the residual amount. Newcomers to the region could buy a pollution right from existing firms. Although the incentive to reduce pollution would exist once this policy were implemented, there would be undesired announcement effects between the time that the measure were proposed and made effective. That is, firms would have an incentive to produce many pollutants upon learning of this policy consideration in order to receive a larger quantity of pollution rights later. Since it would take a long time to enact and possibly clarify (through the courts) such as institutional arrangement, the announcement effect may be important.

Transferability

The announcement effect can be avoided if the idea of pollution rights is combined with the regulatory approach. In the first phase, emission norms for facilities may be specified which implicitly grant a right to pollute up to a specified volume. Then these implicitly defined rights may be made transferable. In the long run, a price for pollution rights would be established, and emission rights would be allocated via the price mechanism.

Duration of Rights

Pollution rights may be defined on a temporary basis or without a time limit. If they are defined temporarily, it may be for a year or according to the life span of the facility. The allocation effects and the practicability of pollution rights may vary with these temporal definitions.

Differences in duration of pollution rights reduces the homogeneity of pollution licenses and thereby impedes emission trading.

An alternative approach is the definition of pollution licenses purely in terms of the quantity of a particular pollutant and with unlimited validity in time. Such licenses function as a specific kind of pollution money with which emissions must be paid: for each unit of emissions the polluter must submit one such emission license to the licensing authority, which is then invalidated and no longer available to justify further emissions. The allocation of pollution with respect to time can in this case be secured by the periodic and possibly reduced supply of the market with new licenses which may be sold by auction.

Integration into Existing Laws

All environmental-policy instruments have to be integrated into the existing legal framework. Very often economists make proposals that are ideal from their point of view but which do not take into consideration existing legal restrictions. In many countries, permits are used as an instrument of environmental policy. These permits specify the maximum amount of emissions allowed by a specific facility or firm per year. Very often they are granted on a temporary basis which is related to the life span of a facility. Furthermore, the permits are frequently granted at virtually a zero price. If these permits were combined with a price tag, a feasible allocation mechanism could be introduced.

Restricting Access to the Regional Labor Market

Pollution rights are a factor of production in fixed supply. If a large firm in a region can get hold of a factor in limited supply, for instance land, it may control access to the region by other firms or the expansion of existing firms.

Similarly, the benefit of buying a pollution right to a large firm may consist in controlling the regional labor market. The large firm is induced to buy pollution rights since this may reduce the output of other firms and, concomitantly, reduce the competing demand for labor in a region (Siebert 1982d; Bonus 1982). Thus, the large firm can increase its labor supply in a region by buying pollution rights.[4]

Capped versus Uncapped System

The pollution licenses discussed so far represent capped systems in which total emissions are limited by an overall ceiling. In contrast to these capped allowances, pollution licenses may also be uncapped. In such a system, the pollution limit is rate-based, i.e., it is a relative emission cap in contrast to an absolute emission cap, for instance grams of a pollutant per mile for a car. A source earns a credit by remaining below a legally set limit and can trade the credit (US Environmental Protection Agency 2001). In such an approach, emissions increase with economic growth.

The Bubble Concept

Some properties of transferable discharge permits have been implemented in the bubble concept, introduced by air-quality policy in the U.S., first in the form of offsets in 1977 and then in the form of the bubble in 1979. As in European air-quality laws, U.S. policy regulates the individual stack by permits and by specifying maximally permissible levels of emissions. The innovation of the bubble concept consists in allowing several sources of emissions to define themselves as a bubble. The emission sources of a bubble have to satisfy the tolerable quantity of emissions of all sources added up so that environmental quality cannot decrease. A single source, however, may emit more than its specific permit allows if another source in the bubble pollutes less. Environmental policy is not interested in the pollution through an individual stack, but in the impact on environmental quality of a bundle of sources. As an example, in one of the first bubbles, a Dupont plant in Chambers, New Jersey, was allowed to neglect 119 smaller process-oriented emission sources of volatile organic components by reducing up to 99 percent (instead of the prescribed 85 percent) at seven major stacks.

[4] The question arises of whether a similar argument holds for the product market. Assume that a sector of the economy happens to be located in an environmental region. Then the large firm may use pollution rights to restrict the output of its competitors. The large firm has an incentive to buy more pollution rights than it needs for production since pollution rights will not be available to its competitors. Consequently, in this case, pollution rights may strengthen the position of a dominant firm.

The advantage of the bubble consists in cost reduction. By allowing abatement where it is cheapest, less resources have to be used for pollution abatement. Also, the bubble concept introduces an incentive to reduce the costs of abatement and to search for new technologies at the decentralized units of the economy. It thus prevents the most important disadvantage of the regulatory approach, namely treating technology as a constant.

Delineation of the Bubble

The creation of a bubble underlies a set of conditions. First, membership in a bubble is voluntary (in contrast to the water association on the Ruhr, see below). Second, the bubble has to respect the given regulation; it cannot pollute a larger total than allowed by permits of the individual sources. Third, emission sources must be near to each other. Fourth, as a rule, the bubble relates to a homogeneous pollutant and not to different pollutants. Bubbles for different pollutants would presuppose that environmental policy can determine the equivalence of different quantities of different pollutants which does not seem practical yet. So far, bubbles refer to three pollutants, namely SO_2, particulates and volatile organic components. Thus, there are restraints in defining a bubble. Whereas efficiency would like to see the bubble relatively large, environmental considerations imply limits on transferability (controlled trading). Finally, hazardous material is subject to binding national emission norms, and trading here is not possible.

It is relatively easy to create a bubble when the emission sources are part of the plant or one firm. The bubble can also be introduced when emission sources of different firms are involved. Then it is a matter of contractual arrangement and compensation payments between the partners involved. Consider a firm with unfavorable abatement costs and a binding environmental restraint. It would be profitable for the firm to induce another firm with a better cost situation to undertake abatement.

Other Forms of Emission Trading

Besides the bubble as described above, three other institutional arrangements should be mentioned.

Offsets. In those areas where the desired environmental quality is not yet established (nonattainment areas), new emission sources wanting to locate must make an arrangement with existing sources by which the increase in pollution is more than offset by abatement at an existing source. By surpassing the emission norms, an existing emission source can establish an "offset"; and it can transfer the offset to a newcomer. Offsets are thus instrumental in improving environmental quality in nonattainment areas; moreover, they allow newcomers to locate in a region.

Banking. Emission reductions which surpass the regional reduction (or overfulfill a standard) can be banked. They then can be transferred at a future point in time, and they can be used in a bubble in the future. The condition is that the reductions are of a permanent nature, that they can be quantified, and that they can be controlled.

Netting. The expansion or modernization of a plant has to satisfy the new source review requirement. Insofar as the additional emissions of an expansion are not too important and if a firm remains within the limits of the bubble, the administrative review of the new source is not necessary. This rule relates both to attainment and nonattainment areas. This is an example of how the time needed for the permit procedure can be cut down.

Some Further Problems

In transplanting the U.S. bubble concept into another institutional setting such as German air-quality management, some problems of the bubble concept emerge.

One problem is that the base line from which emission reductions may be defined is blurred. Permits very often do not define precisely tolerable emissions per year; they may relate to volume flows, and hours of operation per year may not be specified. Consequently, all existing permits would have to be redefined, which represents a sizable task. Moreover, no formal permits may exist for old facilities. Another question is that the bubble concept is difficult to apply in a setting where permits heavily rely on the state of the art with tolerable emissions being not clearly specified. Also, it is difficult for legal thinking to waiver the application of the state of the art if an offset can be provided elsewhere.

Success of Emission Trading

Emission trading has been widely used in the United States (US Environmental Protection Agency 2001). Most prominent are the pollution allowances for sulfur dioxide emissions for electric utilities in the Acid Rain Program. In this program, 6.9 million allowances could be traded in 1999. While trading initially was applied internally in firms, external trading between firms became nearly as relevant as internal trading in the course of the 1990s (US Environmental Protection Agency 2001: 76). Other programs include NO_X budgets for emission sources in many states or for the fleet average of auto makers, standards for industrial air pollution, and chlorofluorcarbon production allowances trading to prevent ozone layer depletion. An interesting example is that some mountain communities in Colorado have introduced Wood Stove and Fireplace Permit Trading. In the European Union, emission trading has been introduced for sources in industry and power generation in 2005. Trading will also be an important mechanism in the context of the Kyoto protocol (see chapter 13).

Institutional Arrangements for Cost Sharing

Besides regulation, emission taxes, or pollution rights, a quality target can be transformed into individual behavior through a mechanism which shares the costs of reaching the targets and simultaneously develops an incentive system that guarantees efficiency. The water associations of the Ruhr area in Germany represent such an approach (Kneese and Bower 1968; Klevorick and Kramer 1973).

The water associations of the Ruhr area (Ruhr, Emscher, Lippe, Wupper, Niers, Erft, Left Lower Rhine, and Ruhr Water Dam Association) represent organizations in which membership is mandatory for every polluter. The general assembly of the association determines the water quality to be attained. When the required environmental-quality level is known, the association can determine the amount of capital equipment, investment, and operating costs that it must spend to attain these standards. Thus, the total costs of abatement are specified. The problem then consists of allocating these costs to the individual polluter. Costs are attributed in such a way that the costs to the individual polluter are related to his quantity (and quality) of pollution. This creates an incentive to abate pollutants.

For instance, the "Emschergenossenschaft" has developed an index that defines the quantity of unpolluted water necessary to dilute polluted water to the level where damage to a test fish is prevented. By this method, a quality target can be fixed; at the same time, different types of pollutants can be expressed in a homogeneous dimension. The formula is (Kneese and Bower 1968, p. 250; Johnson and Brown 1976, p. 123)

$$V = \frac{S}{S^Z} + \frac{B}{2B^Z} + \frac{K-30}{2K^Z} - F \tag{8.1}$$

where V is the dilution factor, S the materials subject to sedimention in centimeters per liter, S^Z the permitted S, B the biochemical oxygen demand BOD_5 in milligrams per liter after sedimentation, B^Z the permitted BOD_5, K the potassium permanganate oxygen ($KMNO_4$) used, K^Z the permitted K in milligrams per liter, and F a coefficient of fish toxicity. Let V_i be the dilution factor for polluter i, and let E_i, be the quantity of wastewater. Then the cost share α_i is given by

$$\alpha_i = \frac{V_i E_i}{\sum_1^n V_i E_i} \quad \text{with} \quad \sum_1^n \alpha_i = 1 \tag{8.2}$$

If total costs are denoted by C, then the cost share for the individual producer is given by $C_i = \alpha_i C$. The polluter can influence C_i by reducing a, that is, by reducing V_i and E_i. Thus, there is an incentive to reduce pollution.

The Ruhr Association uses population equivalents (PEs) as a measure of pollution (Kneese and Bower 1972, p. 60). Dividing the total costs of abatement by the sum of all population equivalents PE, the price p per population equivalent is obtained: $p = C/\Sigma \mathrm{PE}$. The cost share for the individual polluter is given by $C_i = p\mathrm{PE}_i$.

For industrial polluters, the quantity of population equivalents is determined as follows. First, a coefficient of 0.5 PE is used per employee. Second, wastewater is evaluated with 0.01 PE/m^3. Third, special coefficients are used for specific sectors. For instance, 0.85 FE/ton of paper is the coefficient used in paper sulfide production; other examples of coefficients include 31 PE/ton of sulfuric acid used in metal finishing or 0.35 FE/ton of raw cabbage used in the production of sauerkraut. The coefficients vary for the firms within an industry, depending on the production and abatement technology used. For instance, for metal finishing, the coefficient varies between 31 and 6 PE/ton of sulfuric acid used (Kühner 1979). Thus, an incentive is introduced to abate pollutants.

There are some interesting institutional features of the water associations. Voting rights vary with the volume of effluent charges paid and consequently with the volume of pollution produced; thus, the largest polluter has the greatest number of votes. In spite of this rule, analysis shows that the decisions of the associations seem to have been reasonable. Klevorick and Kramer (1973) have researched this problem and have shown that most environmental concerns have been taken care of by the associations. One reason for this success is that institutional safeguards have been introduced. For instance, in the Niers Association, the downstream polluters receive 75 votes before the remaining 225 votes are disitributed according to the paid effluent charges. In the Lippe Association, coal mines cannot have more than 40 percent of the votes.

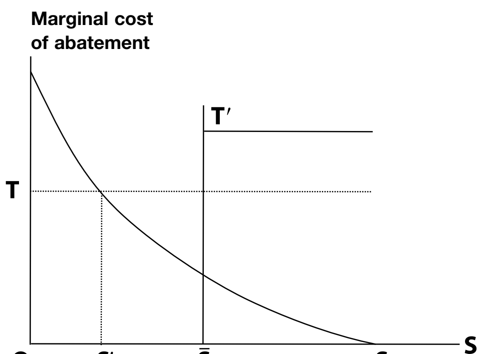

Fig. 8-4. Combining standards and an emission tax

Combining Standards and an Emission Tax

In practical environmental policy, one may want to have the certainty of emission standards and the incentives of an emission tax at the same time. Then a standard and an emission tax may be combined as shown in Fig. 8-4 (Bohm and Russell 1985). A standard $\bar{S}$ limits emissions; for the remaining emissions $O\bar{S}$, an emission tax OT is levied. Such an emission tax introduces an incentive to reduce emissions to OS' and to shift the marginal cost curve of abatement downward. Apparently, such a combination only works if the tax rate OT is higher than the marginal abatement costs to meet the standard. In addition or alternatively, a noncompliance fee $\bar{S}T'$ can be used if the standard is surpassed.

Liability

In principle, liability law is an attractive policy instrument in a market economy. If an individual agent inflicts a damage on another party, liability rules allow the damage costs to be attributed to the agent who caused the damage. Thus, liability will tend to bring private and social costs into line, it also introduces an incentive to prevent damages to third parties. If the originator of a damage can expect to be liable for a damage, he or she will attempt to avoid damages in the first place. In principle, therefore liability is an efficient social institution for dealing with other and third-party damages. Liability *ex post* will be anticipated *ex ante*. Consequently, liability will stimulate new technological solutions. Moreover, liability rules establish an insurance market, and it can be assumed that such a market can generate more imaginative solutions than a regulatory setting.

As a framework of reference, we can consider a situation where the problem of free rider using the environment is nonexistent and exclusive property rights along the lines of the Coase theorem (1960) apply. Then in a world with one polluter and one pollutee and with negligible transaction costs, a liability internalizes risk. If future environmental pollution is to be interpreted as a risk and if polluter and pollutee have an identical risk preference, these measurable stochastic environmental states are converted *ex ante* into deterministic values. Environmental risks are fully anticipated in optimum environmental allocation which appropriately takes quantifiable risk into account. In an ideal institutional arrangement, the polluter behaves as if he were the victim himself.

When transaction costs are explicitly considered, a decentralized application of liability laws will give rise to the following problems.

Legal Costs. Liability law will attribute social costs only *ex post*. With a well functioning institutional mechanism, *ex post* allocation of social costs to the polluter will be anticipated and correctly internalized *ex ante*. If, however, social costs are only allocated with a considerable time lag, the property of efficiency is impaired. Liability law involves the legal process. Especially in the case of continuously occurring emissions, for instance from production, the transaction costs of the legal system tend to be high. It is the characteristics of a market economy that competing uses are not decided by bureaucracies and courts but by the automacy of markets. The environmental problem is a scarcity problem and, consequently, we should attempt to introduce markets. There is the danger that liability law, although establishing insurance markets, increases the role of nonmarket mechanisms of allocation.

Identifying the Polluter. Liability rules require that the polluter can be identified without doubt. Here, however, serious problems arise. There may be many polluters; moreover the potential cause of a damage may stem from different pollutants. Damage is caused by pollutants ambient in the environment; it is difficult to associate pollutants ambient in the environment to emissions. Damages only occur with considerable time lags.

These arguments suggest that, in the case of many polluters and many pollutants, liability rules have to allow an attribution of damages to polluters using statistical probabilities. A problem of long-run damages is that firms only have limited assets and that they may change their legal status or may even cease to exist. It is an open question as to what extent liability laws define exit conditions for firms.

The Extent of Damage. Pollution will not only cause a damage for a specific pollutee, but for a number of pollutees. Here, the problem arises as to whether the damage is to be evaluated individually or by some method of aggregation. Legally and constitutionally, the problem arises as to who has the right to go to court and whether a collective court action is allowed. Besides a damage for more than one person, ecological damages may arise that are not particular to a specific person, at least not today. Liability laws must find a way to account for ecological damages. Moreover, the individuals using the environment as a public consumption good may behave as a free rider when asked to reveal their "true" preferences and their willingness to pay.

Strategic Behavior of the Polluter. The individual polluter may not provide all the information available to him (see principal-agent problem).

Forms of Liability and Incentives. The behavior of the polluter depends on the forms of liability.

– Strict liability implies that parties have to pay damages irrespective of their negligence. Then, they have an incentive to consider all potential harm.
– Negligence rules require a prescribed level of "due" care, and a party is held liable if due care has not been applied.
– Liability with standards only refers to emissions surpassing a standard. In this case, the individual polluter only is liable for pollution beyond the standard.
– Limits of liability may arise from legal statutes or from liable assets of the firm. Such limits represent an upper bound on the care taken.

Burden of Proof. The “burden of proof” is an important aspect of liability law. In the case of strict liability, the burden of proof is with the polluter. He therefore has to carry the transaction costs. In the case of negligence, either the government or the pollutee has the burden of proof.

Insurance Markets. An important ingredient of liability laws is that an insurance market will develop. Then incentives will be introduced into the economic system to prevent pollutants and damages, and with efficient insurance markets, technological information will come to the fore. If environmental damages cannot be attributed to the individual polluter, if the diffusion and the accumulation of pollutants over time are not clearly traceable and if institutional substitutes to specify causality cannot be developed, insurance firms may be reluctant to take over environmental risks. It is a prerequisite for establishing an insurance market that risks can be calculated and that stochastic variables can be transformed into deterministic values. “Creeping” damages (Allmählichkeitsschäden) that only develop over time, do not represent a relevant basis for the insurance industry. These damages are not insurable. This also holds for damages for which a statistical mean cannot be determined, i.e., damages should not be too specific so that risk can be spread by insurance over many cases. Yet another issue is that the risk to which a polluter is exposed is limited by the assets of a firm or other institutional restraints.

Institutional Uncoupling of Compensation from Pollution Taxes. Liability issues have the systematic difficulty that the relationship between emissions and damages can only be established statistically. A specific damage of an individual pollutee and emissions of a single polluter cannot be linked to each other in a causal way. One method of solving this problem in practice is to determine the total level of emissions of all sources, and to identify the actual damage of individuals. This approach is adopted in the environmental compensation principle applied in Japan. Legislation of 1973 required that compensation was paid for certain environmental illnesses according to the severity of the disorder. Damages were not allocated on a causal basis to the polluter. Companies paid a levy into a fund on the basis of their emissions. Those entitled to payments included, for instance, persons who lived in a region where a significant, statistical relationship between air pollution and specific illnesses had been established.

9 Policy Instruments and the Casuistics of Pollution

In the last chapter we have discussed the most important approaches which transmit environmental-quality targets into the abatement behavior of polluters: regulation, emission taxes, pollution licenses, the bubble concept, cost sharing, and liability rules. We now address the issue that the policy instruments that are to be used vary with the environmental problem at hand. The taxanomy of environmental pollution as developed in chapter 2 exhibits a broad spectrum of specific problems. It is therefore worthwhile to analyze policy instruments for the different cases in the casuistics of the environmental problems. Different specific conditions may require different policy instruments.

In our discussion so far, we have used as a base line the case in which emissions arise from stationary sources of production and are released into the environment, with air and water as the environmental media in the foreground. We have developed our analytical framework for this case.

In this chapter, we look at solid waste, emissions from mobile sources, accidental emissions, vintage damages, pollutants in consumption goods, new products, and externalities in land use.

Solid Waste

Waste can be interpreted as a specific type of emission which arises as a joint product in solid form from production and consumption. Unlike other emissions such as CO_2 it no longer can be easily discarded into the environment by the individual polluter. Besides other negative effects an aesthetic deterioration of human living conditions would be the immediate intolerable result. Moreover in contrast to other emissions, the collection of solid waste and some type of management becomes necessary. Waste management may involve recycling, depositing or incineration.

In nuce, our simple model of chapter 3 can be interpreted as covering the problem of solid waste generated by production processes. The pollution-generating function 9.1

$$S^p \geq H(Q) \qquad H'>0, \quad H''>0 \tag{9.1}$$

can be considered to be a function explaining solid waste S^p as depending on output Q. For simplicity, only one sector of the economy is considered.

Output, Q, depends on resource input, R, according to the usual production function

$$Q = F(R) \quad F' > 0, \quad F'' < 0 \tag{9.2}$$

Resources, R^r can also be used to reduce waste, where waste prevented is denoted by S^r

$$S^r = F^r(R^r) \quad F^{r'} > 0, \quad F^{r''} < 0 \tag{9.3}$$

Net waste is defined by $S = S^p - S^r$. A resource restraint $\bar{R} = R + R^r$ implies that there are opportunity costs of reducing waste in terms of forgone production. The opportunity costs of waste not reduced is given by the damage function $U = G(S)$.

In Fig. 9-1, some of these relationships are illustrated. The production function F is depicted in the fourth quadrant. Output, Q, rises with increasing resource input, R. Quadrant I shows waste as a joint product of output. Resources, R^r can also be used for waste abatement. Resource endowment, $\bar{R}$, is given by OK with the 45-degree line indicating the resource restraint. The waste

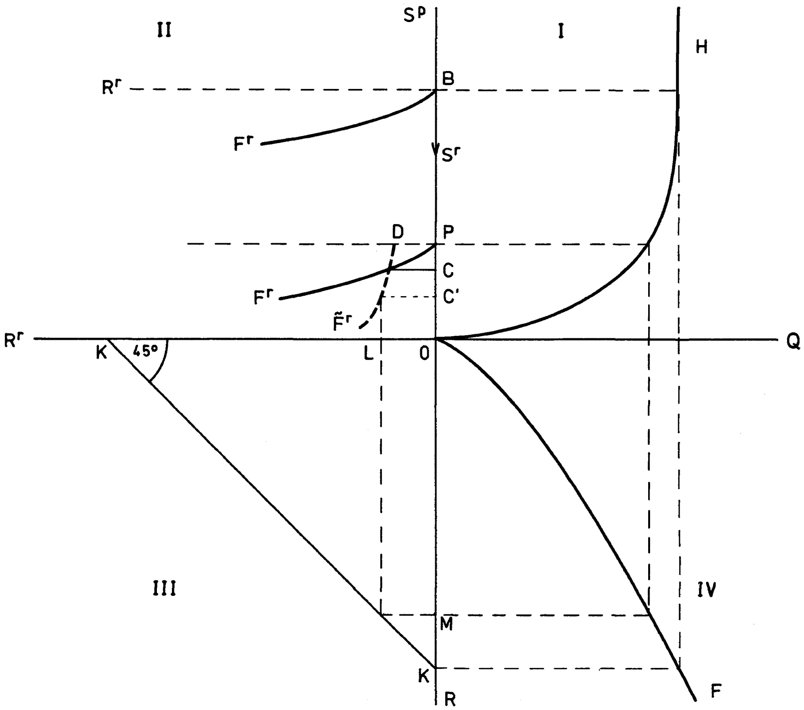

Fig. 9-1. Net waste and production

reduction function is shown by F^r in the second quadrant. Assume OM of the resource R is used to produce ON of the commodity Q. Then waste OP will occur; OL units of the resource are available for waste management. With a given waste abatement function, F^r, PC units of waste can be reduced so that OC units of waste remain.

There is a variety of possible resource allocations between production and waste abatement. If the resource is exclusively used for production, point B shows the total level of net waste. Point B in Fig. 9-1 corresponds to point B in Fig. 3-3. If the resource is partly used for waste abatement, less pollutants arise and environmental quality improves. Moving from B towards the origin in Fig. 9-1 therefore corresponds to moving along curve BGA in the transformation space of Fig. 3-3. Somewhere on line BO, the total resource supply is allocated between production and waste abatement in such a way that all waste is abated. This is the analogon to point G in Fig. 3-3. Thus, the transformation space of an economy incorporates the technical possibilities of waste abatement. Note that the origin of the abatement function always starts at the level of waste generated by the production activity.

Optimal Waste Reduction

The analysis of the problem of waste reduction so far can only be a first step. A more detailed and more realistic description of the problem is required. In addition, an optimum in waste reduction must be discussed.

More realism is introduced, if different types of waste abatement technologies (depositing, incineration) are considered. This has an impact on the transformation space. In Fig. 9-1 consider an alternative abatement technology $\tilde{F}^r$ which requires a start-up use of resources PD before showing results, but exhibits high marginal productivity once the resource use surpasses PD. Then Koopmans efficiency requires to minimize resource input in waste abatement. At the intersection of the two abatement curves in Fig. 9-1, efficiency is improved when the technology $\tilde{F}^r$ is applied. In reality, more than two waste abatement technologies have to be taken into account. Moreover, a vector of different types of waste has to be considered.

Efficiency means that an economy is producing on the surface of the transformation space. Among the efficient points of allocation, an optimal situation has to be chosen. Optimality implies that the impact of waste on environmental quality is evaluated. A simple case is analyzed in Fig. 9-2 where curve OD denotes total environmental damage caused by solid waste. Curve CC indicates cost of waste abatement rising progressively with waste reduced.

OW is total waste given initially. Curve TT describes the net social costs of the level of waste, i.e., the sum of environmental damage costs and of costs of waste abatement. The cost minimum is reached in point S where the marginal damage costs and the marginal costs of abatement are equal (tangents to the curves OD and CC).

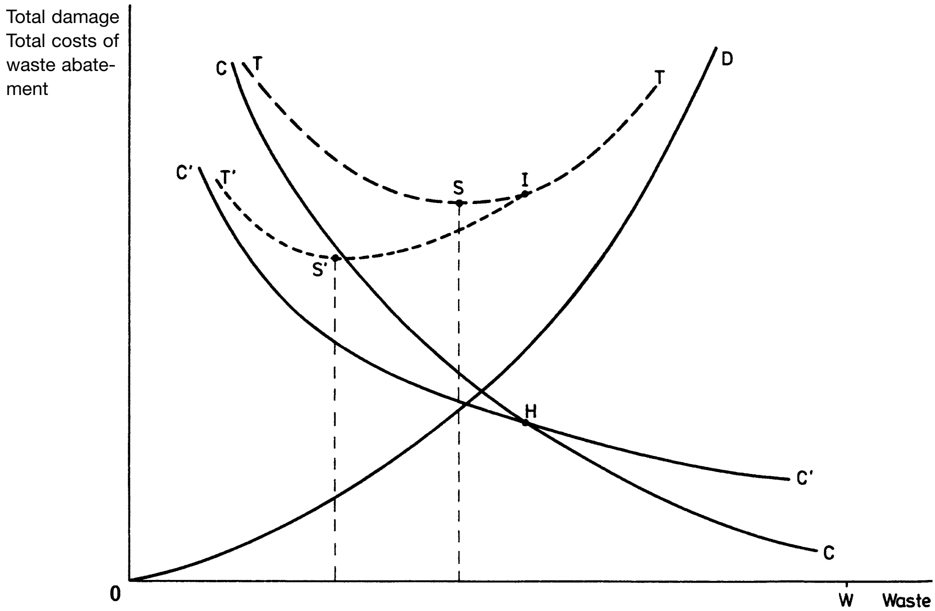

Fig. 9-2. Optimal waste reduction with two cost functions

Consider now a second technology with a cost function $C'C'$ which is more favorable for waste levels left to point H. Then the most favorable cost curve for reducing waste is given by the envelope function CHC' (reading the cost curve from W towards 0). The total cost curve for society including environmental costs is given by the right section IT of curve TT and by the section IT'. The new optimum is at point S' with the more favorable cost function allowing a larger reduction of waste. In the new optimum, the marginal damage must be equal to the marginal cost of the envelope cost curve, i.e., of the relevant section the envelope (tangents to the curves OD and $C'C'$).

In Fig. 9-2, only one type of waste is taken into consideration. In a more realistic interpretation different types of waste must be analyzed. Then, the cost functions CC and $C'C'$ do not only represent traditional resource inputs; costs of waste reduction also must include environmental costs of residuals, i.e., pollutants, such as dioxin, that arise in the waste abatement process. For instance, if waste reduction is interpreted as a production function reducing the volume of waste (more realistically of different types of waste such as household waste, industrial waste or hazardous waste), different types of pollutants remain depending on the waste abatement technology. Landfill versus incineration are cases in point. The ecological costs of these residuals must be factored into the abatement costs.

Establishing Scarcity Prices for Waste with Collection Costs

For practical solutions of the waste problem, a vector of different types of waste and a set of varying waste abatement technologies for different types of waste must be explicitly taken into consideration.

To start from an ideal frame of reference, each type of waste requires a different price. A precondition for such an approach is that the quantities of different waste can be monitored. This may be possible in industry where larger quantities of a specific waste occur. Under these conditions, a negative price may be sufficient enough to initiate a recycling process.

In the case of households, however, it seems to be extremely difficult to apply a price vector differentiated according to specific waste generated. A first prerequisite would be that households are willing to efficiently sort out different waste. A second prerequisite would be that the quantities of different types of waste of households can be measured and monitored. A necessary condition would be that free rider behavior of households in waste disbursement could be policed. This is unlikely. In addition, the costs of collecting waste represent a fixed cost element of waste management. All this implies that charges will involve fixed cost elements that do not establish the right incentives to reduce specific waste. Consequently, environmental policy will have to rely on non-pecuniary incentives such as moral suasion.

Waste Management and Spatial Structure

Complex issues arise, if additional aspects are taken into consideration. So far, we have only studied how the producers of waste, e.g., firms and households, react to waste policy with their quantities of waste. Another important aspect is to which extent municipalities or federal states are willing to provide locational space for waste deposits or for waste incineration.

As an economic principle, scarcity prices should determine where the deposit or the incineration of waste takes place (Michaelis 1993). Regions having capacity for deposits or for the incineration of waste should, in principle, specialize in this activity and collect the corresponding scarcity rent from other regions.[1] Thus, scarcity prices for waste will have to be integrated into the set of scarcity prices for land. Waste management will have an impact on spatial structure.

An interesting implication is that the institutional arrangement of waste management, especially the type of charges, has implications on sorting costs, on the level of waste and on collecting costs, including the transportation costs of waste. All this influences the bid rent functions for land in the Thünen-rings

[1] On ethical limits to this specialization compare the discussion on the export of hazardous wastes.

around the city in the Alonso model (1964). Depending on the waste management applied, different sizes of cities may evolve (Wagner 1993).

Closed Substance Cycle and Product Responsibility

The mass-balance concept indicates that mass taken from the environment must eventually be returned to it (chapter 2). This notion leads to the requirement of a closed substance cycle where the full material balance flow between the environment and the economy is taken into account. General equilibrium models were to analyze the interdependence between product design, recycling, and producer responsibility (Fullerton and Wu 1998; Pethig 2003). In environmental policy, this notion then implies product responsibility of producers and distributors, including importers, at the end of the product's life. In order to implement producer responsibility, institutional arrangements have to be set up in which the products that will not be used any longer are collected, dissembled, and the material contained in them is possibly recovered. Product responsibility implies an incentive to recycle material and to reduce non-recoverable inputs. In such an approach, care must be taken not to discriminate against importers. Then, environmental policy would be an impediment to free trade; within the European Union, it would represent a serious obstacle to the single market.

The German System of Waste Management

Since the beginning of the 1990s, solid waste management has become a major topic of Germany's environmental policy agenda. In particular, several major landfill sites in the former GDR had to be closed down due to environmentally unsound dumping practices in the past thus increasing the already perceptible shortage of landfill capacities. In 2004, a total of 339.4 million tons of solid waste were generated in Germany, of which 65 percent were entered into a recycle and reuse process. The vast majority, 187.4 million tons, came from construction and demolition (with an 86-percent share of recycling), while only 48.4 million tons came from households, 53.0 million tons were linked to production processes and commerce, and 50.5 million tons to mining (BMU 2006).

From the viewpoint of economic efficiency, production wastes are a minor problem since they usually occur in large homogenous quantities that can directly be controlled by those waste-generating firms that have to bear the respective disposal costs. In this case, a tax on waste disposal that reflects the scarcity of landfill space as well as environmental damages would be sufficient to induce an efficient allocation of resources between waste reduction, recycling, and disposal activities. Waste caused by consumption activities pose much more problems to the local authorities since this type of residuals usually accrues in a highly dispersed, heterogeneous, and sometimes even uncontrolled manner. Moreover, in contrast to production waste that is charged by weight or volume, there is only a weak relationship between the individual household's waste generation and its monthly charge bill for municipal waste collection services.

For household waste, the German government relies on the concept of the closed substance cycle and product responsibility of the producer. The basic idea of this approach is to close the product life-cycle by making the producers responsible for their products from the cradle to the grave. In particular, the producers themselves are in charge for recycling or (at least) disposal in an environmentally sound way. Consequently, the costs of waste management are shifted from the consumers (or the public, respectively) to the producers. Since the latter decide on the product's characteristics, this shift in cost is expected to induce a rich variety of product innovations aiming at waste prevention and reduction of toxic material. In addition, the price effects caused by license fees and reprocessing cost are expected to lead to a different relative price system for packaging materials which will then induce a different (and possibly smaller) volume of packaging materials.

In accordance with the "New Waste Avoidance and Waste Management Act" of 1986 and the "Closed Substance Cycle and Waste Management Act" of 1996 landfilling mixed wastes was given up since biological, chemical, and physical degradation processes lead to harmful emissions. Wastes are pretreated, for instance in eliminating harmful metals. Some preference is now given to waste incineration where filter dust is stored in underground mines.

The "Law on Waste Management" of 1986 empowers the federal government to regulate the flow of specific waste products by introducing ordinances that extend the producer's responsibility over the whole life-cycle of their product. A legal ordinance prescribes regulations for taking back batteries and end-of-life vehicles. Batteries containing heavy metals have to be separated from normal household wastes and have to be handed back to retailers who have organized a separate collection system for household batteries. For end-of-life vehicles, a separate system of return points is set up, including disassembly operations and recycling plants. According to the "Ordinance on Packaging Waste", introduced in 1991, a private system for the collection and reprocessing of packaging waste was set up (Klepper and Michaelis 1994). In particular, a specific percentage of the total domestic primary packaging consumption has to be collected, and from this collected material another specific percentage must be sorted out and recycled. The recovery shares reached amount to 80 percent. In the "Duales System," a private non-profit organization manages the collection, treatment, and recovery of all packing alongside the waste management of the municipalities. The system is financed via a license fee (Grüner Punkt, green dot) paid by the packing manufacturers, fillers, and commercial enterprises. At the time when this became effective, packing accounted for about half the volume of household waste and a third of waste weight. The disadvantage if this approach is that it implies a monopoly style organization.

The license fees vary with the actual cost of collecting and sorting the different materials. In 1997, the fees were € 76 per ton of glass, € 204 per ton of paper and cardboard, € 286 per ton of tinplate, € 766 per ton of aluminum, € 1,073 per ton of package compound, and € 1,508 per ton of plastics.

From the viewpoint of overall economic efficiency, mandatory recycling quotas are only second-best policies (Michaelis 1993). In particular, it cannot be ruled out that more or less arbitrarily fixed recycling quotas might be too low or too high from an overall cost-benefit perspective. A more market-oriented approach towards overall efficiency would be to introduce a tax on solid waste disposal. With such a tax, recycling quotas would no longer be necessary. Instead, it could be left to the market mechanism to decide in each individual case whether the collected packaging material should be recycled or disposed of.

In 2003, a new law required distributors to take back cans and non-reusable plastic bottles. The law was considered a countermeasure to the shift away from returnable to disposable beverage packaging. Only when returnable packaging surpasses a market share of 72% can this new law be suspended. The situation is further complicated by the fact that its applicability is specific for each content: instead of the form of packaging itself (non-reusable) it is the current market share of returnable packaging for a particular product such as mineral water or juice that is the trigger. As retailers and producers had failed to have a universally coordinated collection system in place by January 2003, consumers faced an intricate range of solutions. While small retailers accepted cans and bottles only with a receipt of purchase from their own store, some retail chains designed chain-specific packages which could be returned in any of their stores. Some retailers built up their own collection system as "insular solution", four collection systems currently exist independent of distributors. Some retailers have chosen to no longer offer products in cans and plastic bottles that are not reusable. The European Union fears that this institutional arrangement for collection represents a market entry hindrance for non-German producers and has asked Germany to change the system. Particularly kiosks and service stations are said to have lost sales in non-returnable beverages as a consequence of the irritation of customers.

Emissions from Mobile Sources

In contrast to our base line case of stationary sources of emissions, monitoring becomes more difficult when emission sources are mobile. An ideal solution would be that accumulated emissions can be measured by an appropriate technical device, for instance in the exhaust pipe of trucks, cars, planes, and boats. One procedure would be to measure emissions accumulated over a year. Such a technical solution does not seem feasible, yet, although sources from industry indicate that a solution is available. In such an ideal setting, the social costs of automobiles could be attributed to the polluter. Environmental costs would be allocated according to the emissions accumulated per year; in addition, the costs of using the infrastructure (road costs) would be attributed according to the usage of roads. While such an ideal solution is not yet possible, alternative approaches become more attractive such as using inputs as a substitute for emissions, applying product norms for cars and trucks or pulling a tax on pollution-intensive cars.

Mobile emission sources represent a specific problem, if they cross borders and if different national regulations apply. If different national product standards are used, markets will be segmented by raising the opportunity costs of environmental policy. One solution is to attempt to harmonize different national rules. If a consensus on harmonization cannot be reached, inputs may be taxed. This, however, affects emissions only indirectly by reducing demand for the inputs. The problem becomes more complicated, if foreign mobile sources can circumvent national inputs (trucks and cars). Then a charge for using the national infrastructure can be implemented having in principle only a weak incentive for reducing emissions.

Accidental Emissions

Another aspect of our base line case is that emissions occur rather regularly as a joint product of production. Pollutants may arise, however, by accident as in Bhopal, in Seveso, in the Sandoz case or in Tschernobyl. In these cases, which often involve a blow up, the effects of the occurence of accidents are unknown. Consequently, environmental accidents cannot be regulated ex ante because an accident cannot be clearly defined. The polluter-pays principle requires that liability rules are established. Strict liability (Gefährdungshaftung) is the appropriate policy instrument (see chapter 8). Environmental accidents which have no international dimension are primarily a matter for national environmental policy. However, many of the most severe environmental accidents have international repercussions. A recent example are oil spills from tanker accidents. In these circumstances, some form of harmonization of liability rules, including compensation procedures, is needed.

Vintage Damages

A special case prevails, if pollutants have already been in the environment ('old' or historic damages). Then, it may no longer be possible to trace the polluters, for instance in the case of the large number of dumps closed at the end of the seventies in the United States and the Federal Republic of Germany. It may also not be feasible to bring polluters to justice because they ceased to exist, for instance, those who exploited lead mines back in the Middle Ages. The polluter-pays principle cannot be applied, and some type of joint financing of still existing previous polluters (Superfund in the US) or through general taxation is necessary.

Pollutants in Consumption Goods

Pollutants may be contained in products, such as DDT in agricultural goods. A similar problem arises with respect to pharmaceutical products. In these cases of hazardous components in products, third party damages arise in consuming the product.

In circumstances in which the consumption of a product has no adverse effect on anyone other than the consumer, the need for intervention depends on the extent to which the consumer is informed with respect to the characteristics of the product and of the consequences of its consumption. If nonhazardous ingredients are involved, one can rely on consumer souvereignty. In addition, consumer information can be improved by a system of mandatory labelling. In more severe cases, product norms may be applied. Product norms, however, represent a form of market segmentation, giving rise to barriers of trade, especially in an integrated market like the European Union. An alternative to product norms would be liability rules leading to an insurance market; liability, however, would raise transaction costs considerably (see chapter 8).

Pollutants in New Products

If pollutants are introduced into the environment via new products, such as in the chemical or pharmaceutical industry, emission taxes are not effective or practical. Then a licencing procedure may be necessary. Such a process is time-consuming and it impedes the innovative capacity of an economy. Definitely, the time available for a bureaucratic decision should be limited. Under such a condition, a licencing procedure may erect less barriers to innovation than liability rules.

Externalities in Land Use

Environmental problems may arise from different activities being close in space. One activity may be detrimental to the other. In this case, land prices will play an important role as a controlling vehicle which keeps activities apart. If an activity at location x represents a nuisance for the adjoining location y, many mechanisms are available for the owner of activity y to bring about a reduction of pollution at x, including voluntary compensation in the sense of the Coase Theorem and legal litigation. Another approach is the policy of spatial separation through zoning laws.

10 The Political Economy of Environmental Scarcity

In this chapter, we review some of the principles which should govern environmental policy, we study some of the implications of these principles and we indicate why the political process often deviates from them. The center of the stage is dominated by the opportunity cost principle which requires that the opportunity costs of using the environment as a receptacle of waste as well as a public consumption good have to be taken into account. In a decentralized economy, these costs have to be attributed to the subsystems of the economy, for instance through the polluter-pays principle. Additional requirements for environmental policy are the precautionary principle and the principle of interdependence. The chapter also briefly looks at environmental legislation in the last thirty years.

The Opportunity Cost Principle

Scarcity means that there are competing uses. And competing uses imply that opportunity costs arise. These are defined as costs of an opportunity foregone, that is the loss of utility by excluding an alternative use. Economics is the story about opportunity costs. The opportunity cost principle requires that if a scarce resource or good is put to a specific use, the opportunity costs have to be considered. The benefits of a specific use have to outweigh its opportunity costs. The opportunity cost principle guarantees that goods and resources are put to their best use; it is a manifestation of the principle of rationality.

As a guideline for environmental policy, the opportunity cost principle mandates that a specific use of the environment provide benefits that overcompensate its opportunity costs. If the environment is used as a receptacle of waste, the opportunity costs consist in the loss of environmental quality. The use of the environment for assimilative purposes cannot be continued if the opportunity costs, that is, the loss of environmental quality, is greater than the benefits of this use, i.e., facilitating the production of private goods. If, on the other hand, the environment is used as a public good for consumption, the opportunity costs are given by the implied restraint on the assimilative capacity and, consequently, on the production of private goods. Thus, the opportunity cost principle works both ways, it calls for comparing the opportunity costs of using the environment as a receptacle of waste as well as a public good for consumption.

The opportunity costs of using the environment as a free good for public consumption can be easily determined through the evaluation by the market.

Resources needed for abatement, output of private goods foregone, and the loss in national income are all evaluated by market processes. The opportunity costs of using the assimilative services, however, run into the problem of determining the value of a public good, that is of environmental quality lost. As discussed, here the free-rider problem arises. Since the environment is a public good and can be used in equal amounts by all, individuals or groups can take the position of a free rider not contributing to the cost of environmental quality. Institutional mechanisms have to be developed which ensure that free-rider behavior in evaluating environmental quality is reduced. We are far away from ideal solutions in this context (compare chapter 5). The existence of the free-rider phenomenon and lacking institutional mechanisms to prevent free-rider behavior are one reason why the political economy of the opportunity cost principle looks more blurred in reality than in the textbook.

Consider a global environmental good such as the ozone layer (see chapter 13). If a country takes the free-rider position not indicating its willingness to pay, for instance its willingness to reduce carbon dioxide, the value of the ozone layer cannot be adequately determined. Similarly, a group in a society with a strong preference for environmental protection can easily take the position of a free-rider in demanding an especially intense environmental protection if the group does not contribute to the costs of that policy, i.e., if they do not carry the burden. Or, a group not interested in environmental protection may push for a generous use of the environment's assimilative services.

The political importance of free-rider positions will depend on quite a few factors: In the case of a pure public good, the free rider exists. If some of the publicness can be taken away by an appropriate institutional arrangement, for instance by regionalizing the good, part of the free-rider issue disappears. The institutional mechanism of aggregating individual preferences is of importance: A proportional voting system may make it easier for specific groups to influence the environmental quality target than a majority voting system. And the institutional legal framework such as constitutional protection may, admittedly in an extreme case, determine societal preferences by the preference of a specific individual who receives legal or constitutional protection.

The Polluter-Pays Principle

To require that for society as a whole the opportunity costs of a specific resource use should be outweighed by its benefits does not yet specify how the opportunity costs are allocated to the subsystems of a society. For a decentralized economy with autonomous decision making by the subsystems, it is a wise principle to have private benefits of an economic action outweigh its overall opportunity costs to society. The subsystem then carries all the costs arising, both to itself and to the society as a whole. The opportunity costs are allocated to those units that cause them. This is the polluter-pays principle of environmental policy.

The polluter-pays principle is an institutional manifestation of the opportunity cost principle. It can be applied once environmental quality targets are established, and in that sense it circumvents the free-rider problem. The principle has a number of advantages: It allocates the opportunity costs of environmental protection in a reasonable way. The individual polluter has an incentive to reduce pollutants; the divergence between private and social costs is abolished, and commodity prices do include environmental costs as well as traditional factor costs.

A priori, the polluter-pays principle can take many forms such as emission taxes, compensation procedures as in Japan's environmental policy or liability rules. The polluter-pays approach is the documentation of the more general question of an appropriate institutional setting for allocating the opportunity costs of environmental protection to the subsystems. It may also be interpreted as a solution to an incentive problem.

The polluter-pays principle only looks at an institutional mechanism to allocate the opportunity costs of environmental protection. The analogon would be an incentive mechanism for allocating the opportunity costs of environmental degradation to the consumers of the environment as public good.[1]

Apparently, this would be an incentive-compatible arrangement in which the free rider no longer exists and in which the consumer of the environment, by determining the target, would also take into account society's cost to reach the target.

The political economy of the polluter-pays principle shows a whole array of deviations.

As a first condition, the polluter has to be identified. Of course, it is helpful for the application of the polluter-pays principle if that problem can be solved by measuring emissions and removing possible controversial issues into acceptable and practical institutional rules and away from the courts such as in the Japanese compensation schemes. Liability litigation may not be practical. A case in point for a deviation from the polluter-pays principle are hazardous waste already in the environment (old landfills, "Altlasten").

Second, the specific constraints of the policymaker and his vote maximizing behavior will induce him not to apply the polluter-pays principle if it will hurt his constituency. Subsidies and financing through general taxation are less troublesome. Why bother to signal the opportunity costs to the polluter if votes get lost? Similar arguments apply when the polluter-pays principle negatively affects specific sectors of the economy relevant to the policymaker or if it creates regional unemployment.

Third, the policymaker is unwilling to abide by the polluter-pays principle if he is in the upwind or upstream position. In the case of an interregional spillover, there is an incentive to ask for a compensation and to apply the victim-pays principle. Very often, in a lose interpretation, the polluter will display behavior analogous to the free-rider, for instance by claiming that environmental damages are negligible.

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[1] One pragmatic approach in this context is the victim-pays principle or the benefitor's principle (Nutznießer-Prinzip) stressed by Meissner (1985). Note, however, that this principle merely is a way of financing; it does not solve the free-rider issue.

Finally, we meet the free rider again in the case of global environmental goods.

The Pollutee-Pays Principle

The alternative to the polluter-pays principle is the pollutee-pays principle or the victim-pays principle. The notion is that the pollutee has to compensate the polluter in order to induce him to avoid emissions. This concept arises in the context of the Coase theorem. Whereas in a national context with a uniform institutional framework compensation by the pollutee is somewhat unusual, the pollutee pays principle is relevant in transfrontier externalities. Thus, the downstream and downwind country may compensate the upstream or upwind polluter to reduce emissions. De facto, the emission rights then rest with the polluter. Similarly, a country with a strong environmental preference or a high income per capita may compensate the polluting country which has a lower preference for environmental quality. Or a country with a rich endowment in biodiversity may receive compensation from countries for which the biodiversity has a positive value. Finally, this principle may be applied in the case of global media when high income countries place a higher value on preventing climate risks and compensate the lower income countries through payments in order to induce them to avoid pollutants.

The Precautionary Principle

The opportunity costs of environmental degradation or environmental protection cannot be defined in a static setting; they must be defined for a longer time horizon.

With respect to the environment, pollutants accumulate over time (see chapter 15), and damage often will only become apparent with the passage of time. Examples are the accumulation of DDT in food chains, the transport of freon over two to three decades into the ozone layer and the eventual penetration of nitrites into ground water systems. Often, these long-run diffusion functions are not known, and the eventual impact on the environment will only come to light at a later stage. There is uncertainty involved (see chapter 17). Consequently, environmental policy is well advised to also include the long-run opportunity costs of environmental degradation. This requirement implies that environmental policy should not merely consist in responses to pollution, but should be preventive or anticipatory (O’Riordan 1985; Simonis 1983).

Not only must the opportunity costs of environmental degradation be specified in the long run but also the opportunity costs of environmental protection. Abatement activities are capital-intensive, and it takes five or ten years to build up the pollution-control capital (for instance water purification facilities including a sewage transportation system). The adjustment of production processes, changes in the sectoral structure, relocation of firms are phenomena that occur over a decade or more. Continuity of environmental policy is therefore a prerequisite.

A long-run orientation of environmental policy is also relevant because the application of specific instruments takes a long time. For instance, eight years passed between the legislation on Germany's effluent fees in water management (1978) and the application of the full rate in 1986, with at least five additional years of deliberation. As an another example, the state of the art, as defined by German air-quality policy in 1973, was only changed in 1986 after thirteen years.

For all these reasons, the precautionary principle is relevant. It requires to undertake the benefit-cost analysis or the optimization approach over the longer time horizon, including future benefits and costs, option values, irreversibilities and risks.

The demand for a long-run thrust of environmental policy contrasts markedly with the actual environmental policy observed. For instance, the old landfills are an example of a rather short-run orientated environmental policy not anticipating future damage. The policymaker very often has an extremely high discount rate, and critics say, four months before an election it is well above thirty percent. Perceptions on environment problems including public opinion and preferences as established by the political process shift quickly over time, and it seems that the policymaker is tempted to follow such shifts quickly.

The Principle of Interdependence

Environmental systems are interdependent and represent a complex network of interaction. It is commonplace by now that environmental subsystems are related to each other in a multitude of ways. Distinguishing different environmental media such as air, water, or land is only an auxiliary analytical device to grasp the complex problem.

The interdependence of environmental media implies an interdependence among pollutants from the point of view of environmental policy. This interdependence is due to the following reasons:

Pollutants are linked through environmental systems and diffusion between them. Pollutants ambient in the air can be deposited into water systems, and pollutants ambient in rivers, lakes and the ocean can get into the atmosphere by evaporation. Similar relationships exist between air and land as well as water and land. Besides diffusion in a physical sense, for instance through ground water systems, diffusion may occur through ecological systems such as food chains (bio-diffusion).

Pollutants may be linked to each other by the emission technology. A pollutant may either be discharged to the atmosphere, to water system or placed into landfills. The assimilative roles of different media of the environment may be substituted against each other. This also means that abatement technologies are substitutive. If one medium is regulated, emissions may switch over to another medium.

Finally, pollutants may be interrelated through the production technology. If a specific pollutant is reduced, another may increase. For instance, cutting down carbon monoxide in engines is likely to increase nitrogen oxides.

Environmental policy must take these interdependences between environmental media, between abatement, emission and production technologies, and between pollutants into account. If environmental policy addresses itself to only a particular media, a particular pollutant, or a particular abatement or production technology, it is likely to fail in the long run. Very quickly, new problems will pop up. Consequently, environmental policy has to be integrative and encompass all environmental media and pollutants.

As an example in which interdependence was neglected, environmental policy in the U.S. and in some European countries during the early seventies can be quoted from hindsight. Environmental policy centered on air and water quality management, neglecting land and landfills where quite a few hazardous pollutants ended up. As another example, we have lowered the level of larger suspended air-borne particulates in Europe in the late sixties and in the early seventies considerably, only at the expense of increasing thinner particulates and exchanging local pollution by a long-range transfer of pollutants.

The political economy suggests that it is rather difficult to follow a systematic and holistic approach. Policy often is piecemeal and the policymaker adheres to a police power approach, waiting for a problem to develop, to be recognized as an important question by the public including the media, and then stepping in. This behavior leads to *ad hockery*, and the dominating environmental issues shift around.

Major Environmental Legislation

The environmental issue came to the foreground in the sixties, for instance through such diseases as Itai-Itai in Japan, through the eutrophication of lakes, and the decline in air quality. In the late sixties and in the early seventies, legislation for air quality and water management was passed in most of the industrialized countries. Legislation seems to have followed an interesting time pattern. Air quality management was the object of the first major environmental legislation such as the U.S. Clean Air Act (1970) and the gas-lead law (Benzin-Blei-Gesetz 1971), the ambient pollution control act (Bundesimmissionsschutzgesetz 1974, revised 1982), and the technical instructions on air quality (Technische Anleitung zur Reinhaltung der Luft 1983) in Germany. As a second step, legislation for water quality management was introduced such as the U.S. Clean Water Act (1972) and Germany's water management (Wasserhaushaltsgesetz 1976) and effluent fee law (Abwasserabgabengesetz 1976). In a later stage, when some problems of landfills became apparent, the environmental medium land was regulated, for instance through the Superfund in the U.S. (1980) and the Abfallbeseitigungsgesetz in Germany in 1980. A first attempt against waste was the Abfallgesetz 1972 which after several amendments was replaced by the "Closed Substance Cycle and Waste Management Act" (Kreislaufwirtschaft und Abfallgesetz 1996). Moreover, toxic and hazardous materials including product qualities were regulated, for instance in the Chemikaliengesetz (1980) and the Atomgesetz (1980) in Germany.

The initial major laws were revised, for instance the amendment of the U.S. Air and Water Acts in 1977, the introduction of the bubble concept in the U.S., US Clean Air Act 1990, and the new Technische Anleitung zur Reinhaltung der Luft 1986. In these revisions, shortcomings in the protection of the environment were corrected; moreover, it was attempted to introduce more economic incentives; at the same time, environmental regulation came under the attack under the heading of deregulation.

Besides the shift in emphasis on different environmental issues and the issue of deregulation, other aspects have changed the importance of environmental policy. Whereas in the late sixties and early seventies the environmental issue was pressing, in the middle and late seventies and the early eighties, the oil crisis was dominating the political arena. The unusual increase in the oil price represented a supply shock for the world economy, requiring economic adjustments in an institutional setting that had reduced flexibility. Energy conservation was the pressing problem, and alternative energy sources became more important. Environmental constraints, for instance for coal, were not judged so important. With the oil crisis subsiding in the mid-eighties, environmental disruption became more prominent, especially in Europe with Germany's "Waldsterben" giving new fire to the environmental debate. New legislation was passed on large electricity-generating facilities (exceeding a capacity of 50 megawatts) (Großfeuerungsanlagenverordnung 1982) and new rules for catalytic devices in cars were introduced. The German acts on renewable energy (Erneuerbare Energien Gesetz 2000) and power-heat cogeneration (Kraft-Wärme-Kopplungsgesetz 2002) were outcomes of this interest. In the nineties, global warming and the ozone layer represent the main focus. Biodiversity is another important issue.

The European Union has played an important role in defining new property rights for the use of the environment. It has introduced minimum standards for the permissible level of air pollution, water pollution, and waste management. In the 1990s, after the principle of sustainable development was enshrined in the Treaty of Amsterdam (1997) as one of the goals of environmental policy, the EU established a more comprehensive approach to the environment. Through its framework legislation, a number of directives were adopted by member states in the 1980s and the 1990s on water quality, e.g., on drinking water and bathing water quality. The EU also developed standards on ambient air quality assessment, for instance in the Council directives 96/62/EC and 99/30/EC.

The Chemicals Directive *REACH* entered into force on 1 June 2007. *REACH* stands for Registration, Evaluation, and Authorization of Chemicals. About 30,000 substances that are on the European market will be registered with the new *EU* Chemicals Agency in Helsinki. Producers and importers have to develop measures for the safe use of their substances and communicate them to their purchasers. Substances of very high concern are subject to an administrative authorization process. The Chemicals Agency provides non-confidential information on substances and their risks in an Internet database. Consumers will have the right to demand information on whether products contain substances of very high concern.

A review of the different political signals for the German energy industry and their environmental impact is quite telling. “Move away from oil” was the political message at the second energy crisis in 1979/80; energy supply was encouraged to diversify into coal and atomic energy. Electricity was hailed a “pure” energy. Then came the Waldsterben, and coal came under severe pressure. SO_2 reduction was the big issue. Once the firms had adjusted to this orientation in their planning, NO_X received the attention. Then in 1986, Tschernobyl puts into question atomic energy including electricity. In the nineties, the prevention of CO_2 has moved to the foreground. One may wonder which impact on environmental policy the next energy price rise will have. It seems to be rather difficult to have continuity in such a context. Besides these short remarks, it is beyond the scope of this book to study the political process by which environmental policy is formed, to analyze the role of voting and of the voting system, of parties, of party behavior, of pressure groups, of public opinion, of the legal system including constitutional aspects, and of the courts as well as of bargaining behavior in international environmental issues. It seems rather realistic that all these phenomena will imply that actual policy will deviate from the principles such as the opportunity costs principle. There are many reasons in the political arena to forget opportunity costs. It seems the economist’s role to keep stressing the importance of the opportunity costs and of environmental use as an allocation problem.

Part IV
Environmental Allocation in Space

11 EnvironmentalEndowment, Competitiveness and Trade

In the previous chapters we consider a point economy without any spatial dimensions. In this and the next three chapters we introduce the spatial dimension into our analysis. When we take into account the spatial extent of the environmental system, we introduce a set of interesting allocation problems. In the following discussion we study the environmental allocation of spatial systems from a national, global, and regional perspective.[1]

Environmental Systems in Space

Environmental systems are defined over space. Depending on the spatial extent of the environmental media, we can distinguish among the following types of environmental goods.

> *Global environmental goods*, such as the earth's atmosphere or the ozone layer. In this case, the environmental system is used as a public consumer good and as a receptacle of waste for the earth as a whole.
>
> *International environmental goods limited to spatial subsystems* of the world, such as the Mediterranean and the Baltic Sea. These goods extend over at least two nations.
>
> *Transfrontier environmental systems* that transport pollutants from one nation to another (for example, the potassium salt carried by the Rhine River and the acid rains originating in Western Europe and falling on Sweden). Transfrontier pollution can be subdivided into two types: one-way and two-way. One-way transfrontier pollution occurs when the waste from one country is transported to another and environmental quality in the country of origin remains unaffected. Classic examples are the pollutants carried from a source upstream to a location further down the river and pollutants transported by the westerly winds to the east. In two-way transfrontier pollution, waste is also transported back to the country of origin, that is, through atmospheric conditions and changing winds. The

[1] For a more detailed discussion of the international aspect, compare Long and Siebert (1991), Rauscher (1994, 1997), Siebert (1977c, 1978a, 1985), Siebert et al. (1980). Also compare Copeland (1994), Copeland and Taylor (2004), Pethig (1976, 1982).

situation becomes more complex when different pollutants are transmitted through different environmental media.

National environmental goods where environmental boundaries coincide with political frontiers.

Regional environmental goods within one country such as metropolitan air regions or river systems.

Microlevel environmental systems such as small ponds or even smaller units.

Biodiversity can be viewed as a problem on all these spatial levels. It may be considered to be a global good or a national endowment with positive spillovers for other countries.

The existence of different spatial environmental systems implies that we have different types of environmental problems and also that alternative solutions may be necessary for different cases. In this chapter, the interrelation between national environmental endowment and competitiveness is studied. In chapter 12, we analyze transfrontier pollution. Global environmental media are the topic of chapter 13. In chapter 14, regional environmental allocation is discussed.

Environmental Endowment

National environmental goods are characterized by the fact that their spatial dimension corresponds to the political boundaries of a country; that is, the quality of these environmental goods can be controlled by national environmental policy. At first glance, one would not expect such environmental goods to have international dimensions. However, this cursory view is incorrect.

The environment as a public-consumption good can influence the trade position of a country in the service sector (tourism) if the public good limited to national space is a beautiful landscape. The role of the environment as a receptable of waste is even more important. In this function, the environment is a production factor and therefore a determining factor of comparative price advantage. If a country is richly endowed with assimilative services by nature, it will have a trade advantage over a country only scarcely equipped with assimilative services. The abundance or the scarcity of environmental endowment is influenced by the following conditions:

1. The *natural assimilative capacity*, that is, the capacity of the environmental systems to reduce pollutants by natural processes.
2. The *demand for assimilative services* of the environment, measured by the quantity of emissions released into the environment. As we know, emissions depend on consumption, production, and emission technology as well as on abatement technology and abatement incentives.

3. The *value accorded to the public-consumption good* "environment" Evaluation of the environment will depend on preferences, income level, population density, and institutional arrangements for revealing true individual preferences. Instead of assessing environmental quality, a tolerable level of emissions can be established as a target by using the standard-price approach.

If one takes into account differences in environmental endowment among countries, the following questions arise:

Does environmental endowment (or environmental policy) affect the comparative price advantage of a country?

To what extent will a change in comparative advantage influence trade flows, location decisions, the balance of payments, the terms of trade, and the exchange rate?

Does environmental policy in one country has an impact on environmental quality in another country? Does a strict environmental policy in one country imply such a change in international specialization that environmental quality in the other country will decline?

Are gains from trade affected by environmental disruption?

How does the environmental problem relate to trade policy? Do environmental-policy instruments create trade barriers? Can trade-policy tools such as import duties serve to reach environmental targets?

National Environmental Policy and Comparative Advantage

A basic hypothesis explaining trade is that a nation will export a commodity if it has a comparative price advantage in producing that good. Let $p = p_1/p_2$ denote the relative price of the home country in the autarky situation, and let p^* be the relative price of the foreign country. Then the condition for establishing trade is $p \gtrless p^*$. If $p < p^*$, then the home country has a comparative price advantage for commodity 1, and thus it will export commodity 1. If $p > p^*$, then the home country has a comparative advantage for commodity 2, and it will export commodity 2.

Comparative price advantages of the home country for commodity 1 can be explained by the following factors: a more favorable endowment in the home country of the factor that is intensively used in the production of commodity 1, such as capital, labor, or raw-material endowment; a more favorable productivity in the home country in the production of commodity 1 (that is, advantages in technical knowledge which are based on technological, organizational, and management systems as well as on the capabilities of the workforce), and a relatively lower demand for commodity 1 in the home country.

Environmental abundance or scarcity is also a factor which influences the comparative price advantage of a country. Assume that the home country pursues an environmental policy because the given environmental quality is not acceptable. Assume further that an emission tax is levied. Then we know from Eq. 7.13 that, under some conditions, especially when $H_1'F_1' > H_2'F_2'$, we have $dp/dz > 0$. In a closed economy, the relative price of the pollution-intensive commodity increases if an environmental policy is undertaken. This means that the comparative price advantage of the home country is reduced. The competitive position of the country is negatively affected, and exports will be reduced.

The Heckscher-Ohlin theorem can be extended to trade with pollution-intensive commodities. The Heckscher-Ohlin theorem states that given identical demand and identical technologies among countries, a country richly endowed with a factor of production will export that commodity which heavily uses the abundant factor. Let the home country be richly endowed with environmental services. Let z represent the correct indicator of environmental scarcity; that is, assume that environmental policy finds the ideal or correct shadow price. If we assume that the home country is richly endowed with environmental services, we can express this situation as $z < z^*$, where z is the emission tax of the home country and z^* is that of the foreign country. Because $dp/dz \geq 0$, we have $p(z) < p^*(z^*)$ if $z < z^*$, so that the environmentally rich country will export the pollution-intensive commodity. The country with limited environmental attributes will export the commodity which is not pollution-intensive.[2]

Figure 11-1 explains this argument. $AGBCH$ represents the transformation space of the home country as it was derived in Fig. 3-3. In order to keep the diagram simple, we do not show the transformation space of the foreign country. Rather, we indicate its production block XYZ where environmental quality is not explicitly considered for the foreign country. Furthermore, the production block is drawn scaled down for simplicity. Note that the production block of the foreign country XYZ lies horizontally in the UQ_1Q_2 space.

We want to analyze different cases. First, assume that no environmental policy is undertaken and that the home country commences trade. Point F denotes the autarky situation in which relative prices diverge so that $p < p^*$. In order to interpret the diagram, we assume that the home country is a small country so that the foreign country dictates the relative price p^*. Assume that the trade equilibrium is given at point F', where the production block of the foreign country is tangential to the transformation space of the home country. The home country specializes in the production of commodity 1. This happens to be the pollution-intensive commodity. As a consequence of international trade, the home country will produce more of the pollution-intensive commodity, and environmental quality will decline. Remember, we are assuming that no environmental policy has been instituted yet.

Second, assume that the home country is in autarky (point F), that is, that there is no trade. Then if environmental policy is undertaken, p must rise since the environmental costs of production are attributed to the pollution-intensive commodity 1. The home country will move up the transformation space (starting from point F) and have a lower comparative advantage. In Fig. 11-2, curve $B'C'$ represents the projection of the transformation curve onto the Q_1Q_2

[2] It is conceivable that the comparative price advantage is "turned around" by environmental policy. In such a case the home country would export the environmentally favorable product.

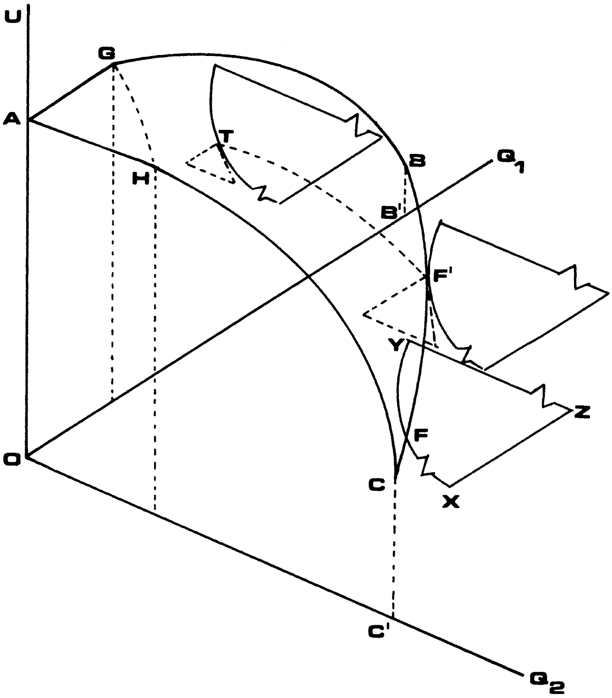

Fig. 11-1. Trade effects of environmental policy

plane in the case of no environmental policy. Curve $B'C'$ can be taken from Fig. 11-1. Point F represents the autarky situation. Curve DD' is a transformation curve for a higher environmental quality. Point F'' is the new autarky point. When $tg\alpha' > tg\alpha$, it signals that p has risen and that the home country's comparative advantage has declined.

Environmental Policy and Trade Flows

In the previous two cases, we analyzed situations in which the home country was in autarky initially, let us now consider a trade equilibrium in the initial situation. A reduction in the home country's comparative price advantage indicates that potential exports of the pollution-intensive commodity will fall. If we want to analyze the change in actual exports arising from environmental policy, we must start from an initial trade equilibrium and ask how the trade volume will be affected by environmental policy.

In Fig. 11-1, this problem can be expressed as follows. Consider point F', which denotes a trade equilibrium without environmental policy. How does environmental policy of the home country affect this trade equilibrium?

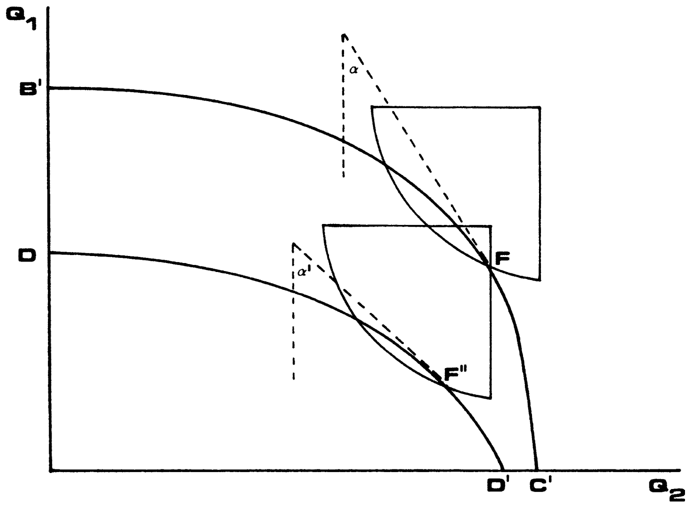

Fig. 11-2. Comparative advantage and environmental policy

In the initial situation F' the trade flows are shown by the trade triangle at point F'. If the home country pursues an environmental policy, its export advantage will fall. One can expect that the export quantity of the home country will decrease.

If we assume that the home country is small, the relative price p of situation F' will be dictated by the foreign country. In this case, we can define an isoprice line for constant $\bar{p}$ and alternative emission tax rates for the home country. This isoprice line $F'T$ indicates the adjustment process which will occur in the home country. The export quantity is reduced for a given relative price. The imports also have to decrease. The trade triangle depicted by the triangle drawn at point T becomes smaller.

In our analysis so far, we have used an emission tax as the environmental policy instrument. The results also can be retained if environmental policy fixes the tolerable level of emission. Then, in Fig. 11-1, environmental policy cuts horizontally through the transformation space defining the ambient quality strived for. Neglecting the diffusion function, this is equivalent to defining a quantity of tolerable emissions. When the emission licenses are tolerable the same solution as in the case of the optimal tax will be reached (for instance point T in Fig. 11-1). In a tradeable permit system, the Rybczynski theorem can be applied (Rauscher 1991). The production of the pollution-intensive good is reduced whereas the production of the other good is increased.

If we assume that the home country is not small, then p becomes a variable. Under these conditions, the environmental policy of the home country will lead to an increase of p in the world market. Thus, the new trade position, which takes into account the home country's environmental policy, lies to the left of the isoprice line $F'T$. Because of this influence by the home country on relative price p, its comparative advantage is reduced even more. A formal analysis of this problem for a two-country model is given by Siebert (1979a) and Siebert et al. (1980).

The basic idea of these models is to introduce equilibrium conditions of the world market and the budget constraints. The equilibrium conditions of the two-country case require that the world markets be cleared, that is, that the excess demand of both countries add to zero,

$$E_i(p_i, z) + E_i^*(p_i^*) = 0 \tag{11.1}$$

where E_i^* denotes the excess demand of the foreign country. For the commodity prices of the home country p_i and the foreign country p_i*, we have

$$B = -(p_1 E_1 + p_2 E_2) \tag{11.2}$$

where w specifies the exchange rate (for example, with the dimension of dollars per German mark). The balance of payments B is defined as

$$B = -(p_1 E_1 + p_2 E_2) \tag{11.3}$$

Total differentiation of Eq. 11.1 through 11.3 with respect to z answers the question of under which conditions environmental policy affects the variables in the system.

1. If constant exchange rates are assumed, the system of equations tells us how the balance of payments changes with environmental policy.
2. If flexible exchange rates are assumed, we obtain information about the changes in the exchange rates (revaluation or devaluation).
3. In both cases one obtains statements about the change of commodity flows and variations in the terms of trade.

Environmental Policy, Imperfect Competition and Trade

In models of imperfect competition, the theoretical results on environmental allocation change somewhat. In a pure monopoly, less is produced so that the monopolist appears as the environmentalist's friend (Solow 1974). This comes at a social cost because of suboptimal output (Requate 2006). Policy instruments like an emission tax will further decrease the output level. The social welfare loss as a result of decreased consumption possibilities may outweigh gains from reduced pollution. Hence, making producers fully internalize their pollution damage by an emission tax or tradable permits may not be socially desirable (Carraro 1998: 367). In models of contestable markets with different product preferences of consumers and economies of scale in production, consumers have more choice; environmental impacts then represent one aspect of product quality. Consumers may be willing to pay more for products that are more friendly to the environment (Conrad 2002b). It can be shown that economies of scale may mean less inputs and consequently less pollution. Learning by doing may partly substitute material input, thus reducing emissions. Contestable markets may induce technical change and thus lead to endogenous growth that does not increase environmental impact. Also, in the context of WTO, banning the use of quotas and tariffs as policy instruments, governments may be tempted to engage in strategic behavior by using environmental regulation instead. Strategic environmental policy in the form of lax standards (i.e., marginal abatement cost is priced below the marginal cost of pollution) can enhance the competitiveness of domestic exporters in imperfectly competitive markets. This however is only a second-best policy, while export or R&D subsidies are more efficient instruments (Barrett 1994b). Applying environmental policies to oligopolistic industries may lead to ambiguous results (Rauscher 2005).

Location Advantage

The change in comparative price advantage indicates variations not only in potential trade flows but also in location advantage. If environmental policy is pursued in countries poorly endowed with assimilative services, then the production conditions of the pollution-intensive sector will be negatively affected. Its production costs will rise. At the same time, the relative location advantage of an environmentally rich country improves. If capital is internationally mobile, one can expect that, *ceteris paribus*, capital of the environmentally poor country will be transferred to the environmentally rich country. The effects of environmental policy on the location advantage will also depend on the type of policy instrument used. An emission tax will serve to correct relative prices and will change comparative advantage; a permit system will be likely to make location space temporarily unavailable, and thus it may have much stronger effects on location.

International Specialization and Environmental Quality

In the case of transfrontier pollution, environmental quality of the foreign country is influenced by the pollutants which are transferred from the home country to the foreign country by environmental media. The environmental policy of the home country can, however, affect environmental quality in the foreign country even if the home country's pollution is confined to national environmental media. This comes about by specialization and trade. For example, assume that the home country introduces an emission tax and thereby impairs its comparative price advantage for the pollution-intensive commodity. Its exports will fall, and the production of the pollution-intensive commodity will be reduced. A reallocation of resources takes place. However, resource use is increased in the abatement process while resources are withdrawn from the pollution-intensive sector. Production in the environmentally favorable sector is expanded. In sum, the environmental quality of the home country has to increase.

What kinds of adjustment processes take place in the foreign country which does not pursue an environmental policy? Since the comparative price advantage of the home country deteriorates for the pollution-intensive commodity, the comparative price advantage of the foreign country rises. It is profitable for the foreign country to increase the production of this commodity. In the foreign country, a reallocation of its resources occurs in favor of the pollution-intensive commodity so that emissions increase and environmental quality abroad worsens. In short, the environmental policy of the home country negatively affects the environmental quality in the foreign country through specialization and by trade.

Does this “pollute thy neighbor via trade” thesis mean that the home country can impose detrimental environmental conditions on the foreign country? For instance, can the industrialized nations export their pollutants to the developing countries via trade? Is this a new type of imperialism, a “pollution imperialism”? Can the industrial countries engage in ecological dumping driving the pollution-intensive industry out of their territory and thus driving it to the third world? The answer to these questions is no, for the following reasons.

First, environmental policy involves costs for the concerned nations, namely, in terms of the resources used as well as the target losses in other policy areas (unemployment, the loss of the comparative price advantage). A country is only willing to tolerate these costs of a better environmental quality to a certain extent.

Second, the costs of a better environment (costs of pollution abatement) increase progressively, thereby placing severe limitations on environmental policy. Third, the environmentally rich country can protect itself by introducing environmental-policy measures. By imposing such measures as emission charges on polluting products, the environmentally rich country will reduce the attractiveness of these goods for international trade and thereby avoid specialization in the production of environment-intensive products. In this way, the environmentally rich country can maintain or improve the quality of its environment. Note that the “pollute their neighbor via trade” argument as also appeared as the leakage effect in the context of global public goods (Rauscher 1997). Take CO_2 emissions. If they are prevented in one country, industry may relocate and produce emissions in another country.

The Equalization of Prices for Emissions

Under certain conditions, the emission tax will adjust itself at home and abroad in the long run. Assume that environmental policy reacts to a change of environmental scarcity in both countries and that it correctly reflects environmental scarcity. The home country is assumed to be scarcely endowed with environmental services and the foreign country richly endowed in this respect. Then, in the initial situation, the emission tax is high at home and low abroad. For a high price of environmental use the home country will specialize in a more environmentally favorable production; conversely, the foreign country, having a smaller emission tax rate, will endeavor to specialize more in the production of pollution-intensive goods. The environmental quality increases in the home country and decreases abroad. In the long run, *ceteris paribus*, the emission taxes have to approach one another through international trade and through specialization. A key assumption in this prognosis is that these countries have the same production technology. If this condition is not valid, then the emission taxes are not likely to converge. Note that identical shadow prices do not imply identical environmental qualities.

Factor mobility between two areas (nations, regions) also works towards the equalization of environmental shadow prices. Assume that commodities are immobile and that traditional resources (labor, capital) are totally mobile between two areas and infinitely divisible while the environment is an immobile factor of production. Then the emission tax will adjust itself in the long run between the areas. The mobility of labor and capital will be sufficient to equalize the price of the immobile factor "environmental abundance" assuming identical and linear-homogeneous production functions for each sector in the two regions.

This tendency of equalization of the factor price of the immobile factor of production through the mobility of other factors of production or the exchange of commodities, however, does not work, when the mobility of labor also depends on regional environmental quality and when the evaluation of environmental quality is determined by individual preferences (majority voting). Individuals will migrate to the area with a better environmental quality and increase the demand for environmental goods there, raising the emission tax. In the vacated area, however, the demand for environmental quality will decrease and the emission tax has to fall there. Due to the fact that labor mobility depends on the wage rate and on regional environmental quality, the labor market may be segmented. The polluted area may have a higher wage rate and a lower emission tax; the emission tax may not be identical between regions. Apparently, this argument is more relevant in an interregional context, for instance in a Tiebout scenario (1956).

Environmental Policy and Gains from Trade

The "pollute thy neighbor" thesis points to an important, previously neglected aspect. The primary motivation for engaging in foreign trade is the prospect of gains, that is, that countries expand their consumption opportunities through trade. If a country exports the pollution-intensive commodity, it reduces its environmental quality. So, in this case, the traditionally defined gains from trade with regard to commodities 1 and 2 have to be compared with the deterioration of environmental quality. Trade pays for an economy only when net welfare increases, that is, when the traditional gains from trade overcompensate the deterioration of environmental quality. From this consideration it also follows that in an open economy, the reduction of the gains from trade can be considered as target losses of environmental policy.

This argument can be clarified through Fig. 11-1 where F is the autarky situation and F' is the initial trade equilibrium without environmental policy. Engaging in trade, that is, moving from F to F', creates gains from trade as indicated by the trade triangle at F'. The home country can reach a consumption point outside its transformation space. Pursuing environmental policy, that is, moving from F' to T, implies a higher environmental quality and a smaller trade triangle. The shrinking of the trade triangle can be considered to be an indicator of smaller gains from trade in the traditional sense. It can be shown that the emission tax has to be set in such a way that the net (marginal) welfare gains of introducing an emission tax are zero (Siebert 1977c).

If the home country exports the less pollution-intensive commodity, it will improve its comparative advantage by implementing an environmental policy. Its gains from trade will be increased for given terms of trade.

In the discussion so far, we have not considered the case where the home country may influence its terms of trade. Assume that the home country exports the pollution-intensive commodity. Then its terms of trade will improve if environmental policy reduces excess supply of the commodity at home and if excess supply of the import commodity is increased. We know from the traditional gains-from-trade discussion that a high price elasticity of demand for the pollution-intensive commodity and a low price elasticity of supply at home represent such conditions. Similarly, we must require low import demand and high export supply elasticities abroad.

Up to now, trade theory has not taken into account environmental degradation in defining the gains from trade. Gains from trade should, however, be specified as the net improvements in well-being, rather than in terms of consumption availabilities. It then becomes necessary to weigh traditional gains from trade against environmental degradation. An open economy must be prepared to accept lower traditional gains from trade for the sake of an improved environmental quality.

Environmental Pollution: A Race to the Bottom?

As environmental endowment is a determinant of comparative advantage, a country may be tempted to accept pollution in order to improve its competitiveness for exports. The country then uses pollution as a strategic variable in its trade policy. Alternatively, a country may make itself more attractive for capital in locational competition by putting less weight on pollution control. If all countries behave that way, they will accept more environmental pollution. It is feared that this non-cooperative Nash game will imply a race to the bottom. Note that this hypothesis is the opposite of the pollute-they-neighbor via trade thesis.

In an approach with pollution as a strategic variable in trade policy and locational policy, the optimal volume of pollution abatement, as determined in a country's benefit-cost analysis, is higher because the country can have gains from trade or a larger capital stock by pollution. It increases its competitiveness or it will prevent capital outflow or attract capital. So there is more pollution. The Nash equilibrium is not Pareto-optimal (Van Long and Siebert 1991: 306). Note that the hypothesis of a race to the bottom is related to the leakage argument in case of global goods (see chapter 13).

However, the hypothesis of a race to the bottom does not have too much empirical validity. The country will hurt itself in terms of more pollution by following this approach. In any case, there cannot be a race to the bottom if the country puts some value on environmental quality. So there is a lower bound on environmental deterioration as in other forms of locational competition (Siebert 2000, 2002, 2006). Moreover, the approach presupposes that the voters of a country have no or nearly no interest in environmental quality or that the political decision-making process is dominated by the export industry. Furthermore, the hypothesis neglects that export firms and many multinationals have an interest in their ecological reputation abroad so that they will not be inclined to actively pursue such an approach. This especially holds for firms with products at the final stage of production, catering for the consumer. Finally, national trade policy is restricted by international rules including WTO procedures; in the European Union it is no longer in national hands.

Empirical Studies of the Impact of Environmental Policy on Trade

There is no final word on clear-cut empirical econometrically backed evidence that environmental policy has led to a change in trade patterns and in the relocation of industries (Rauscher 1997, 2005). Studies test different hypotheses, apply different methods, and use different data including different time periods (Copeland and Taylor 2004). A main problem is that pollution data are scarce and that there is not much movement in environmental data, because environmental policy instruments only vary slowly over a longer period. Another problem is that environmental quality improves with income growth and that income growth is linked to trade. Moreover, technology is improved reducing pollution. For these reasons, it is difficult to find a negative impact of trade on environmental quality (Dean 2000; Beghin and Potier 2003). Quite a few studies cannot establish such a relationship. Thus, it is found that trade in goods is not influenced by pollution abatement costs (Tobey 1990; Grossman and Krueger 1993; Jaffe et al. 1995; Frankel and Rose 2002; Unteroberdoerster 2003; Managi 2006a,b). According to Murrell and Ryterman (1991), the hypothesis that trade is not influenced by environmental policy cannot be rejected. The reason for these results is that environmental costs are only a very small part of product costs. Thus, empirical data indicate that for most industries in the US pollution abatement costs are less than 2 percent of operating costs (Low 1992; OECD 2005). Applied general equilibrium models find no evidence that developing countries tend to have a comparative advantage in pollution-intensive goods (Perroni and Wigle 1994; Dean 1996). Whereas the terms of trade are negatively affected by environmental policy and competitiveness is reduced, the income effect goes the other way. Factor endowment is found to be a major cause of comparative advantage of industrial countries in emission-intensive goods but a strong technological effect reduces pollution (Antweiler et al. 2001).

Surprisingly, quite a few empirical studies even established a positive relation between trade and environmental quality. Besides the positive link between trade and income and the demand for a better environmental quality, another aspect is that countries with a lower preference for environmental quality benefit from the improved pollution abatement technology and improved products in the more environmentally minded countries. Furthermore, reducing import restrictions including national subsidies will reduce output in old industries with old technologies of industrial countries and pollutants stemming from them. Thus, if the world produces at its efficient spots, pollution will be reduced. The production of agricultural goods and of coal in industrial countries such as Germany are excellent examples (Rauscher 1997). In addition, in specific pollution-intensive sectors the terms-of-trade effect is more relevant. Whereas these sectors are affected by environmental policy, the impact of environmental costs on trade is superseded by many other determinants of trade, such as technological progress, increase in labor costs, and the catching up of developing countries. For specific products such as ebony (Barbier 1991) environmental policy is important, of course.

Besides the terms-of-trade effect and the income effect, trade has to be distinguished from foreign direct investment. Studies of direct investment in pollution-intensive industries such as the chemical industry suggest an impact of environmental policy (Rowland and Feiock 1991). Laxity in environmental policy is found to be a relevant determinant of foreign direct investment of pollution-intensive industries (Kolstad and Xing 1998). But looking at a broader spectrum of sectors no clear-cut pattern emerges. Some authors find support for the pollution haven hypothesis according to which a lax environmental policy in developing countries attracts pollution-intensive foreign direct investment (Birdsall and Wheeler 1992; Becker and Henderson 2000; Keller and Levinson 2002). With the empirical evidence in all these areas being weak it is no surprise that the answers to policy questions are ambiguous (Rauscher 2005).

Trade Policy as a Means for Environmental Protection?

Ecologists demand that trade policy instruments should be used in the arsenal of environmental policy.

Barriers to Trade to Protect the Environment? One general argument is that world trade is associated with economic growth and that economic growth generates pollution. Consequently, barriers to trade are considered to be helpful in improving the environment. This argument is wrong. Environmental protection should be undertaken by environmental policy instruments because these instruments express environmental scarcity and introduce incentives to reduce pollution. Barriers of trade, be they import taxes or quotas, can only affect environmental quality in a very indirect way. They would be instruments in the world of the n-th-best compared to specific environmental policy instruments. An expansion of world trade only can be harmful from the point of view of the environment, if appropriate environmental policies are lacking. Trade liberalization therefore must not be associated with a deterioration of environmental quality if the correct environmental policy is undertaken. Trade policy cannot substitute environmental policy. Besides, trade increases welfare and this makes it easier to protect the environment. With higher national income achieved by trade, the opportunity costs of a given environmental policy are reduced. An increased welfare or a higher income from trade will also raise the demand for a better environmental quality if the income elasticity of demand for environmental quality is larger than unity.

Barriers to Market Access to Induce Environmental Policy Abroad. On the less general level of argumentation, trade policy instruments such as an import tax or a quota are proposed, if a product is produced abroad with a higher pollution intensity than at home. The import tax or the quota then are intended to induce the foreign country to apply a similar environmental policy as the home country. With the same motive, product norms are favored by ecologists making market access for the foreign country more difficult or impossible. Using trade policy instruments as a crowbar to force other countries to a similar environmental policy is a misleading concept. This approach does not take into account that the environment, if pollution only occurs domestically, is a factor of endowment like any other factor. Therefore, environmental abundance or scarcity should be included in determining comparative advantage like other traditionally recognized factors, such as resources, technical know-how, and so on. Countries richly endowed with the factor "environment" should specialize in those products which use the environment more intensively. Countries less richly endowed with the environment should specialize in the production of goods that need less of the environment. If ecologists demand a level playing field in the interpretation of having the same (strict) environmental policy everywhere they ignore the concept of the international division of labor and of the merits of specialization. This also holds if countries have the same environmental endowment, for instance the same assimilative capacity, but different preferences. Assuming the environment is a national good, different national preferences should play a role, as in other allocation issues. A country should not force its preferences on other countries.

Protecting the National Environment through Trade Policy. Another issue is when a country wants to protect its environment which may be affected by imported products. Here the casuistics of the environmental problem becomes relevant. Consider the case that a country imports an investment good which – when used – generates pollutants. In this case, the normal environmental policy instruments, such as emission taxes, transferable permits or even regulation can be applied. Product norms limiting trade are not necessary. If pollutants, such as pesticides or hazardous material are contained in consumption goods or in pharmaceutical products, improving the information of consumers (see chapter 9) or product norms may be appropriate strategies. Product norms, however, erect barriers to trade.

Environmental Concerns – A Pretext for Protection

Environmental concerns may be used as a pretext in order to introduce protectionist devises, either through import taxation or product norms or through export subsidies. Whereas ecologist demand the same environmental policy everywhere – so to say a level playing field in an ecological interpretation – the business community requires a level playing field from the firm's point of view. Business wants the same conditions in each country. If firms in the other countries are facing less strict environmental rules, business wants "a level playing field" for the producers at home. Domestic import-competing sectors ask for import taxes or quotas for products that have been produced with a higher pollution intensity abroad. Or, pollution-intensive export sectors at home which lose their comparative advantage due to environmental policy ask for compensation or countervailing measures to make up for the loss of their relative position.

If these political demands are satisfied, environmental policy will give rise to new trade distortions. The idea of the international division of labor will be violated. As was already pointed out, environmental abundance or scarcity is the factor in foreign trade which should be included in determining comparative advantage like other traditionally recognized factors. It would not make sense that pressure groups with strong interests (export and import industries, unions) succeed in inducing governments to compensate national industry for the environmental advantages of other countries through trade-policy measures. By levying tariffs on imports or subsidizing their own exports, environmentally poor countries should not attempt to protect their domestic industries that produce pollution-intensive goods. This would jeopardize their own environmental policy measures. The costs of such a policy are bound to be high in the long run since such a policy means that each country will try to compensate its comparative disadvantage by policy measures. A country poorly endowed with labor will protect itself against labor-intensive imports; a country poorly endowed with capital will protect itself against capital-intensive imports; a country poorly endowed with technical knowledge will protect itself against technology-intensive inputs. And a country poorly endowed with environmental services will protect itself against pollution-intensive goods. In such a scenario, the idea of the advantage of international specialization is dead.

Environmental Policy and World Trade Order

International rules for trade and investment have evolved without explicitly taking into account environmental protection. The institutional arrangement for the international division of labor, laid down in the norms of the General

Agreement on Tariffs and Trade (GATT, now the World Trade Organization), attempts to provide a multilateral economic framework in which the exchange of goods and the movement of resources can flourish so as to increase the wealth of nations. Environmental policy has as its main aim the protection of the natural living space of mankind and the integration of environmental scarcity into economic decisions. Both policy areas thus relate to defining the institutional framework for decentralized economic decision-making (Siebert 1996).

When the environment can be treated as a national public good, environmental policy is consistent with the precepts of the international division of Labor. In the international division of labor, it is quite normal for national prices for immobile resources to differ. The environment is one such immobile national resource. Price instruments are therefore ideal for expressing scarcity; they do not serve as trade barriers.

The consistency between national environmental policy and international trade rules as institutional arrangements for efficient international resource allocation becomes less clear when additional aspects of environmental policy are taken into account. One such aspect concerns pollutants arising from non-stationary sources of production. Examples include pollutants embodied in consumer goods or released in the use of consumer goods and emissions from mobile sources.

The Freedom to Apply Environmental Policy Instruments

The rules of the World Trade Organization (WTO) allow national governments to apply a variety of environmental policies, including emission taxes (with border adjustments in the form of rebates for exports), permit systems, refund schemes for recyclable waste etc. (GATT, 1992). The important proviso is that these policies must not create unnecessary obstacles to trade, that is, they must not discriminate between domestic and foreign products. "GATT rules … place essentially no constraints on a country's right to protect its own environment against damage from either domestic production or imported products. Generally speaking, a country can do anything to imports or exports that it does to its own products, and it can do anything it considers necessary to its own production processes" (GATT, 1992, p. 23).

Principles to Prevent Obstacles to Trade

Trade, however, will be distorted if a country whose environment and welfare are harmed by imports containing pollution, or releasing pollution during use, protects itself by taxing pollutants, by taxing the imports, or by applying product norms. In such cases, imports create domestic consumption externalities against which remedial measures may be lawfully applied under WTO rules. Yet, such measures would generate uncertainties in the international division of labor.

Therefore, establishment of rules and commitment to those rules are necessary in order to increase transparency and to prevent environmental policy from being used as a protectionist pretext. Thus, a WTO framework with some skeleton rules for trade in environmentally sensitive products is needed in order to avoid a segmentation of world markets.

The following guidelines may be instrumental in reducing the conflict between environmental and trade policy:

(i) *Principle of First-Best Solution*. Clear dividing lines should be established between trade policy and environmental policy. Trade policy instruments should not be used for environmental protection; environmental policy measures should not be applied in trade policy. On principle, first-best instruments should be used in each policy area.

The principle of First-Best Solution may also be called *The Principle of the Appropriateness of Means*. As such, it is consistent with GATT Article XX. Policy instruments should be chosen such that unnecessary distortions are avoided. Trade policy instruments should be regarded as inappropriate if, for example, emission taxes are available that address an environmental problem directly. Should trade measures nevertheless be taken into consideration, then measures which are least intrusive on trade, that is, least restrictive, should be applied. This may also be called *The Principle of Least Trade Restrictiveness.*

(ii) *Principle of Non-Discrimination*. Environmental policies should discriminate neither among WTO contracting parties nor between imported and domestic products (national treatment). This line has already been developed in the Thailand cigarette case of 1990. An exception to non-discrimination is GATT Article XX, which, under certain conditions, permits health, safety, and domestic resource conservation goals to dominate the national treatment criterion. However, in order to comply with the most-favored-nation clause, "bound" tariffs can only be raised by re-negotiation according to GATT procedures.

(iii) *Principle of Necessity*. In deciding whether an exception to WTO obligations can be made, WTO panels will decide whether an instrument is "necessary", i.e., whether a departure from WTO rules is unavoidable. This necessity test has the purpose of narrowing exceptions. The list of exceptions in Article XX is exhaustive; in order to reduce exemptions, the burden of proof lies with the party invoking Article XX.

(iv) *Principle of the Limits of Territorial Sovereignty.* Policies to protect the national environment and to conserve a nation's resources, as justified under Article XX, should not be extended to another nation's territory. Countries should not aim environmental or trade measures at environmental conditions or production and processing externalities in other countries.

(v) *Principle of Country-Of-Origin.* With respect to product standards and norms for production processes, use of the rules of the importing country (principle of destination) erect trade barriers. Therefore, the country-of-origin rules should be applied. As a general rule, a country importing a product should not apply its environmental standards to the production processes of another country. This principle was established in the Mexican tuna case (GATT 1992, p. 15).

(vi) *The Principle of Determining Product Similarity from the Demand Side*. Similarity of products from purposes of non-discrimination ("like products" in WTO language) should be determined from the demand side rather than the supply side. The relevant criterion should be a high elasticity of substiution in demand, rather than similarities in the technical aspects of producions.

Ethical Restraints for Exports

Should countries apply weaker environmental standards to exports than to products used at home, when pollutants are contained in those goods or released during their use? This question is particularly relevant to trade in toxic wastes. Here the ethical answer is in the biblical tradition of "do not do unto others what you do not want done to you" or according to the Kantian imperative "Act so that the maxim of your will can be valid at the same time as a principle of universal legislation" (see chapter 5). As a matter of principle, rules and procedures in use domestically should be applied to exports. This can be interpreted as an application of the country-of-origin principle. In the case of toxic waste, it implies that waste should be exported only if the environmental standards of the exporting country are satisfied. It is clear that the use of this criterion does not preclude exports of waste to countries endowed with better deposit conditions.

Global environmental issues are different from national issues and thus require different solutions (see chapter 13).

Trade Policy to Solve Transfrontier and Global Pollution Problems?

When transfrontier or global externalities exist (see chapters 12 and 13), again the taxonomy of the environmental problem is relevant. In the standard case when emissions are generated in production and are transmitted to other countries or to a global system, the usual environmental policy instruments such as emission taxes or permits are to be applied. A precondition is some type of agreement between countries. If a consensus on the quantity of emissions to be abated exists and if the total quantity is allocated to individual countries, for instance through unilateral reductions, the relocation of industry from countries with a stricter environmental policy to pollution heavens would not violate the overall target. The pollution heaven can only allow pollutants to the extent of its quota. Trade restrictions are, in principle, the wrong instrument.

A more complicated question is to what extent trade policy instruments should be used as a bargaining threat in order to induce countries to abide by multilateral agreements (see below).

Another case in the taxonomy of the environmental problem is the protection of fauna and flora to which most of the trade provisions in multilateral environmental agreements apply. According to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) a trade ban has been put on ivory. Import bans are used by certain countries for whales, fur seals, migratory birds, and other species.

Table 11-1. Selected core multilateral environmental agreements

Agreement type and name	Date adopted	Secretariat
Atmosphere Conventions:		
United Nations Framework Convention on Climate Change (UNFCCC)	1992	UN
Kyoto Protocol to the United Nations Framework Convention on Climate Change	1997	UN
Vienna Convention for the Protection of the Ozone Layer	1985	UNEP
Montreal Protocol on Substances that Deplete the Ozone Layer	1987	UNEP
Convention on Long-Range Transboundary Pollution	1979	UNCE
Biodiversity-related Conventions:		
United Nations International Treaty on Plant Genetic Resources for Food and Agriculture	2004	UN
Convention on Biological Diversity	1992	UNEP
Cartagena Protocol on Biosafety to the Convention on Biological Diversity	2001	UNEP
Convention on International Trade in Endangered Species (CITES)	1973	UNEP
Chemicals and Hazardous Wastes Conventions:		
Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal	1989	UNEP
Regional Seas Conventions and Related Agreements:		
Convention for Cooperation in the Protection and Sustainable Development of the Marine and Coastal Environment of the Northeast Pacific (Antigua Convention)	2002	UNEP
Convention on the Conservation and Management of Fishery Resources in the South-East Atlantic Ocean, Windhoek	2001	UNEP
Global Program of Action for the Protection of the Marine Environment from Land-based Activities	1995	UNEP
Convention for the Protection of the Mediterranean Sea against Pollution (Barcelona)	1976	UNEP

Source: UN Environment Programme (2007)

Elements of a Multilateral Environmental Order

There are at least 502 documented international treaties and agreements relating to the environment, the majority of them being regional in nature, including 70 percent of the 302 agreements negotiated since 1972. The largest grouping of multilateral environmental agreements has been those relating to the maritime environment, accounting for over 40 percent of the total, and composed primarily of regional agreements (UN Environment Program 2001). For a survey of environmental multilateral agreements see Table 3.1 A in Finus (2003).

A multilateral environmental order has to be consistent with a multilateral rule system for trade and investment; it has to reduce or prevent frictions between the two rule systems arising in the case of national and global environmental goods.

Rule consistency between environmental and trade agreements. Environmental agreements and trade agreements have evolved independently from each other. From 1933 to 1990, 127 multilateral environmental agreements were concluded out of which 17 had trade provisions, especially in the area of protecting fauna and flora (GATT 1992, Table 11-1). The WTO lists 31 multilateral environmental agreements containing potential trade measures, regulating or restraining the trade in particular substances or products, either between parties to the treaty and/or between parties and non-parties. Trade measures include reporting requirements on the extent of trade in a product, labeling or identification requirements, moving permits or consent requirements, specific import or export bans restricting trade with certain states, general import or export bans on a product, and measures such as taxes or subsidies intended to alter dynamics of trade in a product (Brack and Gray 2003). It can be expected that environmental agreements will play a larger role in the future. Inconsistencies between institutional arrangements for trade and for the environment should be prevented:

- Both systems of rules must be based on the common target of reducing inefficiencies and distortions; the internalization of environmental cost is one method to reduce distortions.
- Voluntary agreements are to be preferred to prohibitions.
- Rules must be clear, so that conflicts are minimized.
- The use of instruments restricting free trade due to environmental concerns such as import bans on endangered species should be limited to specific cases.
- All members of WTO should be induced to adhere to international environmental agreements.

No waiver. In the history of GATT, policy areas with large complexities not easily resolved at multilateral levels were exempted from GATT rules. Thus, a waiver was applied in agriculture, in trade in textiles, and in preferential trade agreements. It would be costly to follow such an approach for environmental issues. Policy issues where waivers have been used have proven to be a permanent source of friction in the past; moreover, as agriculture and preferential trade agreements show, exemptions have involved departures from the most favored nation principle. Plans to make waivers temporary could not be sustained. Since, unlike agriculture, the environment cuts across all sectors, an environmental waiver does not represent a sectorial exemption; disputes in this area would more or less affect the complete spectrum of the international division of labor.

Dispute settlement procedure. The procedure for dispute settlement of the WTO should be extended to the environmental arena. Procedural rules, if agreed upon, can help resolve conflicts. Agreements on principles are important in establishing rules for the world economy.

Environmental Policy in the Single Market

An argument often heard is that firms in a Single European Market need the same starting conditions in order to compete and that different national environmental regulations would distort competition. This argument of levelling the playing field is, however, a fallacy.

In order to disentangle the political demand that firms need the same starting conditions everywhere from its economic core, let us differentiate between environmental quality and environmental policy instruments.

First of all, if environmental media can be interpreted as national public goods, for instance a river system specific to one country or noise pollution, that target can be determined on the national level. The trade-off between environmental quality as a public consumption good and as a receptacle of emissions is then a purely national problem similar to the endowment with other factors of production. Then, the national policy process can evaluate the tradeoff between the benefit and cost of preventing pollution.

Second, there is the question to what extent environmental policy instruments such as emission taxes or pollution licenses should be uniform. These policy instruments represent a cost factor and can be interpreted as a production tax for pollution-intensive activities. The country undertaking environmental policy will negatively affect its comparative price advantage and its absolute price advantage. Clearly, the loss of comparative advantage represents an opportunity cost to the country undertaking environmental policy. It can be left to the political preferences of the individual European country to what extent it wants to reduce its absolute and comparative price advantage. The principle of the country of origin can be applied. The environment is an immobile factor of endowment like land and most types of labor. It is quite normal for prices of immobile factors to differ between countries, and different prices for an immobile factor endowment do not require harmonization.

Third, the argument of leveling the playing field contains a grain of truth for the single market where national markets should not be segmented by environmental regulation such as product standard or licensing. Segmentation of markets is counter to the principle of integration. The advantage of prices for emissions is that prices do not erect market entry barriers and do not segment markets.

Fourth, decentralizing environmental policy is in line with the subsidiarity principle which requires to undertake economic policy at the level that can solve the problem most efficiently. The subsidiarity principle is an aspect of fiscal or regulatory federalism and fiscal equivalence (Olson 1969). The issue is to find the appropriate institutional level for policy. The subsidiarity principle and fiscal federalism are principles guiding the organizational structure of society. In this context, in a single market like the European Union a decision has to be made on which tasks should be assigned to which level. In some areas discussed above institutional integration can be brought about by institutional competition as a device to integrate different national institutional arrangements.

A different story are transfrontier pollution problems (see chapter 12). Besides environmental pollution from stationary sources, there are other cases of environmental policy requiring different types of solutions. Thus, emissions from nonstationary sources (transportation) can move across borders. Then emission taxes can be used, and these emission taxes can diverge between nations if the mobile sources do not move across national borders too often (tourism). If, however, the sources move frequently as in the case of trucking, emission taxes have to be harmonized. As long as monitoring costs are too high, product norms for transportation equipment are the relevant policy means. Apparently, national differentiated product norms for cars and other mobile sources of emission would introduce trade barriers. Therefore, product norms have to be harmonized within Europe in order to prevent market segmentation.

Pollutants may be contained in products to be consumed; third parties are not affected and we do not have the case of a technological externality but a merit argument. Then, product norms are used for consumer protection. Here, the potential for decentralization depends on the confidence in consumer sovereignty and on the evaluation of the pollutant contained in the consumption good.

When environmental systems of a European dimension are involved or when the European Union negotiates on global environmental goods as the Earth's atmosphere in the issue of global warming, the decisions shift to the European level.

12 Transfrontier Pollution

In the previous chapter, the repercussions of a country's environmental policy on the environmental quality of another country through the international division of labor were studied. But countries may be interlinked more directly via environmental media, for instance through river systems or atmospheric media or they may use an international public good jointly. Then the issue arises how the economic decisions in one country affect environmental quality in the other country or the jointly used public good. In this chapter, transfrontier issues are analyzed. The noncooperative and cooperative solution of transfrontier pollution media are discussed. Policy measures are reviewed.

Transfrontier Diffusion Function Versus International Public Good

Transfrontier pollution and global issues have the common feature that countries are directly linked to each other via environmental media. For analytical purpose it is worthwhile, however, to distinguish transfrontier pollution and global environmental systems (Siebert 1985). Transfrontier pollution is characterized by a diffusion function T with environmental quality in one region j being determined by emissions not only of region j, but – via the diffusion function T – also by emissions of region i.

$$\boldsymbol{U^j = G^j(E^j, T(E^i))} \tag{12.1}$$

For instance, T may be uni-directional. In contrast, for an international public good k, the diffusion function cannot be explicitly defined. The international public good k is used in equal amounts by all, its quality being determined by emissions in j and i and we have

$$\boldsymbol{U^k = G^k(E^j, E^i)} \tag{12.2}$$

Apparently, the international public good can be interpreted as a special case of transfrontier pollution[1] where the diffusion function T is not explicitly considered. In order to give the problem more structure and to discuss different policy solutions for the two cases, it is worthwhile to explicitly distinguish the cases of transfrontier pollution and global environmental media. Transfrontier

[1] In a formal sense, one can always find a function H so that $G(E^j, T(E^i)) = H(E^j, E^i)$.

pollution is the theme of this chapter. Global environmental media will be discussed in chapter 13.

Distortions from Transfrontier Pollution

Transfrontier pollution represents an externality between countries and implies a distortion. The upstream or the upwind country sends pollutants via the environmental media to the downstream or downwind country. This implies a severe distortion (see chapter 14). The polluting country reduces its ambient level of pollution by sending pollutants abroad, thus reducing the opportunity costs of environmental policy and increasing its comparative advantage for pollution-intensive activities. In the pollution-receiving country, the ambient level of pollution is increased and the comparative advantage of pollution-intensive activities is reduced. Thus, the distortion refers to environmental allocation as well as to sectoral structure.

Without a solution to transfrontier environmental problems, national environmental policy operates under the conditions of an international distortion. This has several implications. The opportunity costs of protecting the environment in the downstream or downwind country are too high. This limits the scope of environmental policy and reduces the optimal environmental quality strived for. Moreover, the obstacles to environmental policy may be increased by pointing to transfrontier pollution; environmental policy has to find its reason in being the forerunner for other countries, as in the German case, hoping for an international demonstration effect and for other countries to follow.

The Noncooperative Solution to Transfrontier Pollution

In the noncooperative solution each country maximizes its utility (or minimizes its costs) separately; the upstream country does not take into account transfrontier pollution. Note that the two countries are interpreted as separate units with their own preference functions and their own abatement functions. The countries are linked via transfrontier pollution. Let environmental damage depend on pollutants ambient in the environment with S_o^1 denoting gross emissions before diffusion and abatement, T pollutants transferred from region 2 to region 1, S_r^i pollutant abated and C^i costs of abatement.

One procedure to analyze the noncooperative and cooperative behavior of upstream and downstream country is to let them maximize their utility (Eq. 4.1) subject to the restraints of the transformation space developed in chapter 3. This would be rather cumbersome. In order to simplify the analysis we assume that countries minimize their total costs, i.e., the sum of environmental costs or damages and abatement costs. This requires to explicitly introduce a damage function D with

$$D = D(S) \qquad D' > 0,\ D'' > 0$$

with damages increasing with pollutants ambient in the environment. Damage is expressed in monetary units so that damage function and abatement function have the same dimension. Note that the damage function 3.5 has to be interpreted differently. Under these assumptions, the upstream country 2 minimizes its total cost

$$\text{Min } D^2(S_o^2 - T(S_r^2) - S_r^2) + C^2(S_r^2)\ . \tag{12.3}$$

It is assumed that the initial levels of pollution, S_o^1 and S_o^2, are given. With the transfer of pollutants not being considered, the optimality condition requires for the optimal reduction level $\hat{S}_r^2$

$$-\frac{dD^2}{dS_r^2}(S_o^2 - T(\hat{S}_r^2) - \hat{S}_r^2 = \frac{dC^2}{dS_r^2}(\hat{S}_r^2) \tag{12.4}$$

Note that

$$\frac{dD^2}{dS_r^2} = \frac{dD}{dS}\frac{dS}{dS_r^2} < 0$$

because an increase in pollutants increases environmental damages and because the reduction of pollutants reduces pollutants ambient in the environment. The downstream country minimizes

$$\text{Min } D^1(S_o^1 + T(S_r^2) - S_r^1 + C^1(S_r^1)) \tag{12.5}$$

where pollutants ambient in the environment of region 1 are influenced by transfrontier pollution. Optimality requires for the optimal reduction level $\hat{S}_r^1$

$$-\frac{dD^1}{dS_r^1}(S_o^1 + T(S_r^2) - \hat{S}_r^1) = \frac{dC^1}{dS_r^1}(\hat{S}_r^1) \tag{12.6}$$

The optimality conditions 12.4 and 12.6 mean that prevented marginal damage is equal to marginal cost of abatement. Equations 12.4 and 12.6 mirror the noncooperative equilibrium if S_2^r equalizes $\hat{S}_2^r$.

In a noncooperative solution with each country optimizing separately, the optimality condition implies that the upstream country considers pollutants transferred abroad as a substitute for abatement. Consequently, its incentive to abate is relatively low as shown by point A in Fig. 12-1. For the upstream country, the transfer of pollutants $S_o^2 S_o^{2'}$ can be interpreted as turning the abatement function leftward. If country 2 abstains from abatement, i.e., if $S_r^2 = 0$, $T = T_o$. Abatement reduces the concentration of the pollutant in the environment and hence transfrontier diffusion declines ($dT/dS_r^2 < 0$). If all emissions are abated, such as under the application of a perfect filter system, there

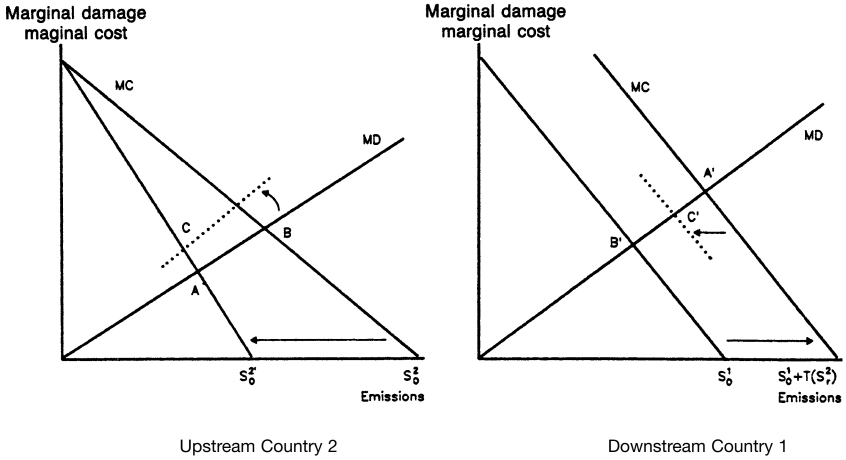

Fig. 12-1. Transfrontier pollution

is no diffusion across borders. It can be argued that pollutants transferred abroad are proportional to pollutants ambient and, consequently, of pollutants abated. Therefore, the marginal cost curve in the reference case of abatement and in the case of transfrontier pollution intersect on the cost axis. Comparing the two marginal cost curves for country 2 in Fig. 12-1 an international transfer of pollutants can be interpreted as a costless reduction in the initial level of pollution.

For the downstream country, however, the import of pollutants via environmental media increases the "initial" level of pollution and shifts the cost curve to the right according to $T(\hat{S}_r^2)$. Optimal abatement is at point A' in Fig. 12-1.

An alternative illustration with reaction functions is shown in the $S_r^1 - S_r^2$-space in Fig. 12-2. Equations 12.4 and 12.6 implicitly define the reaction functions of the two countries. For the downstream country, 1, there is an implicit relation $R^1(S_r^2)$ between emissions abated in country 2 and in country 1.

I_o^1 and I^1 are indifference curves of country 1. In this setting, indifference curves represent combinations of S_1^r and S_2^r which produce the same total costs consisting of damage and abatement costs.

These indifference curves must have an extremum on the reaction function R^1 by the definition of the reaction function. This extremum is defined by a situation in which marginal prevented damage and marginal costs of abatement are equal for a given abatement level of the other country. Consider country 1 with point A where the optimum is reached. If less pollutants are abated, i.e., if S_r^1 is smaller than in the optimum, marginal costs of abatement are smaller, but marginal damage is higher. As a net effect, marginal net benefit is smaller than in the optimum. Then, abatement costs are too high. Thus, if one moves from point A to the left, costs in country 1 rise, an indiffer-

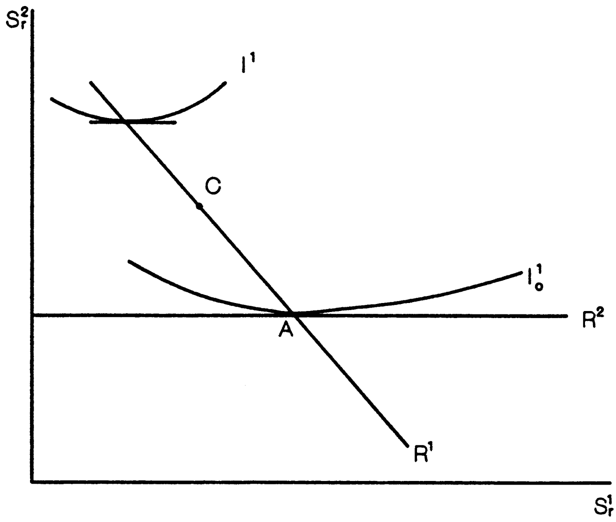

Fig. 12-2. Noncooperative and cooperative solution to transfrontier pollution

ence curve of equal costs or equal utility requires, that country 2 abates more pollutants. This also holds, if more pollutants are abated than in the optimum. Consequently, the indifference curve has the shape as shown in Fig. 12-2.

Indifference curves further to the north represent higher utility levels for country 1 as for given S_r^1 higher abatement activities in country 2 imply a smaller import of pollutants to country 1.

The slope of the reaction function is negative. This can be seen from Fig. 12-1. The less country 2 abates, the more the marginal cost curve of country 1 shifts to the right. As the marginal damage is increasing in emissions (concentration), country 1 will react with an increase in its abatement efforts.

For the upstream country 2, pollutants in the other country do not influence the level of abatement. Its reaction function R^2 is independent of the abatement level in country 1. Note that R^2 is also an indifference curve of country 2 because reductions of country 2 do not enter country 1's damage function. Therefore, R^2 is the indifference curve of country 2 for the minimum of its total costs. Other indifference curves of country 2 not depicted in Fig. 12-2, are parallel to R^2. An indifference curve further away (both north and south) indicates lower utility levels.

The noncooperative solution is given by the intersection of the reaction functions in point A of Fig. 12-2. It follows straightforwardly from Fig. 12-2 that the noncooperative solution in the transfrontier case does not represent a situation in which one or both of the countries has an incentive to change its position. In point A, country 1's indifference curve I_o^1 is tangent to country 2's indifference curve R^2 (which also is its reaction function). Intuitively, any isolated change in abatement efforts of country 1 would necessarily worsen the utility of the downstream country and any isolated or coordinated change in abatement efforts of the upstream country would necessarily worsen that country's utility. A Pareto-improving reallocation of abatement activities is therefore impossible under the given conditions. Nevertheless, there is scope for improvement if the institutional arrangement changes.

The Cooperative Solution to Transfrontier Pollution

If we allow side payments, at least one country can reach a higher utility level. In a cooperative solution both countries optimize jointly. Such payments then redistribute the increase in utility (Kuhl 1987; Mohr 1990c). Joint minimization of costs[2]

$$\text{Min}\, D^1(S_o^1 + T(S_r^2) - S_r^1) + D^2(S_o^2 + T(S_r^2) - S_r^2) + C^1(S_r^1) + C^2(S_r^2) \tag{12.7}$$

yields[3]

$$-\frac{dD^1}{dS_r^1}(.) = \frac{dC^1}{dS_r^1}(.) \tag{12.8}$$

$$-\frac{dD^1}{dS_r^2}(.) - \frac{dD^2}{dS_r^2}(.) = \frac{dC^2}{dS_r^2}(.) \tag{12.9}$$

As before, abatement in the downstream country 1 benefits only that country. Hence, as before, joint cost minimization requires that the downstream country's marginal abatement equals its marginal damage costs (Eq. 12.8).

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[2] For the case of a global public good without an explicit diffusion function compare Hoel (1991). For an explicit transfrontier model compare Kuhl (1987).

[3] More explicitly Eqs. 12.8 and 12.9 are written as

$$-\frac{dD^1}{dS_r^1}(S_o^1 + T(S_r^{2*}) - S_r^{1*}) = \frac{dC^1}{dS_r^1}(S_r^{1*})$$

$$-\frac{dD^1}{dS_r^2}(S_o^1 + T(S_r^{2*}) - S_r^{1*}) - \frac{dD^2}{dS_r^2}(S_o^2 - T(S_r^{2*}) - S_r^{2*}) = \frac{dC^2}{dS_r^2}(S_r^{2*})$$

Using $E^1 = S_o^1 + T(S_r^2) - S_r^1$, $E^2 = S_o^2 - T(S_r^2) - S_r^2$ and omitting the optimal abatement levels enables us to rewrite Eq. 12.9 as

$$-\frac{dD^1}{dE^1}\frac{dE^1}{dT}\frac{dT}{dS_r^2} - \frac{dD^2}{dE^2}\left[\frac{dE^2}{dS_r^2} + \frac{dE^2}{dT}\frac{dT}{dS_r^2}\right] = \frac{dC^2}{dS_r^2}$$

for which $dE^1/dT = 1$ and $dE^2/dT = -1$.

However, contrary to the noncooperative case, under joint cost minimization it is taken into account that abatement in the upstream country benefits both. Joint cost minimization therefore requires that marginal abatement cost equals the sum of marginal damage costs in both countries (Eq. 12.9). Taken together, Eqs. 12.8 and 12.9 imply that under joint cost minimization marginal abatement costs in the downstream country must necessarily be larger than those upstream. This need not surprise in view of the downstream "windfall" associated with upstream abatement.

Comparing Eqs. 12.4 and 12.9 and taking into account that $dD^1/dS_r^2 < 0$, it follows that under joint cost minimization the abatement effort upstream exceeds that under the noncooperative solution. Hence, in Fig. 12-2 the joint cost minimum is located above R^2. Furthermore, the joint cost minimum must be located on R^1 as R^1 represents the optimality condition 12.6 which is identical to 12.8. In Fig. 12-2 joint cost minimization is located in a point like C. Hence, compared to the noncooperative solution A it requires greater abatement efforts upstream and smaller efforts downstream. In Fig. 12-2, the marginal damage curve of the upstream country shifts upwards because the impact of transfrontier pollution on the downstream country is taken into account. Relative to A, more pollutants are abated. In the downstream country 1, pollution to be abated is reduced.

Side Payments

An immediate question arises as to how this cost-reducing reallocation can be brought about. After all, we know that any movement from A in the direction of C by a pure reallocation of efforts reduces utility in the upstream country. The answer to this is "side payments". The role of side payments can be illustrated in Fig. 12-3 which assumes that transfers are interpreted as cost reductions, i.e., they enter both countries' utility by a unity marginal utility.

Costs associated with the noncooperative solution A in Fig. 12-2 are represented by the origin in Fig. 12-3. A movement along R^1 in the upward-left direction in Fig. 12-2 corresponds to a movement from A in the direction of K in Fig. 12-3. Such a movement reduces costs to country 1 but increases costs to country 2.

The negative section of the horizontal axis measures the reduction in benefits of country 2, if country 2 were to undertake abatement at home. This would mean less diffusion of pollutants to country 1, i.e., an increase of benefit there. With the usual properties of the abatement function, i.e., declining marginal productivities, and of the damage function, i.e., increasing marginal damage, the curve AK indicating the distribution of changes in benefits between the two countries by reallocating abatement, is concave. Note that contrary to the case of a global environmental good there is no lense of mutual advantages for both countries in Fig. 12-3 (compare Fig. 13-3).

Side payments from 1 to 2 can be represented by a line with slope –1 starting on the curve AK in Fig. 12-3. For example, suppose actual abatement is

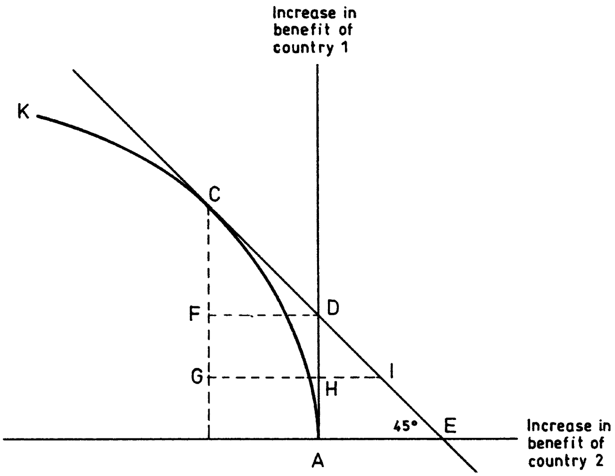

Fig. 12-3. Reallocation of abatement efforts and side payments

represented by *C* in Fig. 12-3. Without side payments, costs would be represented by *C*, too. Obviously such an agreement on cost minimization could never materialize as 2 loses compared to noncooperation in *A*. This disincentive to cooperate can be mitigated by side payments from 1 to 2, separating the location which represents actual abatement costs from the costs (gains) associated with cooperation. While abatement costs still remain in *C*, the gains of cooperation are represented by points on the line through *C* in the direction of *E*. Larger side payments are represented by points on the line *CE* closer to *E*.

Interestingly, there is a range of side payments from which both countries can gain. In point *D*, the upstream country 2 would incur the costs of abatement *FD* which would represent a loss of benefit for it. It would be compensated by a side payment of the same amount, i.e., by *FD* = *FC*. Country 2 would improve its situation relative to point *A*. Thus, cooperation benefits only the downstream country while higher abatement costs upstream are exactly set off by the side payments country 2 receives. In *E*, only country 2 gains while the side payments that country 1 pays exactly set off its gains from lower environmental costs. In points between *D* and *E* both benefit from cooperation. Consider for instance point *I*. The upstream country incurs the additional costs *GH*, but it is compensated by *CG* = *GI* and receives a net benefit *HI*. The downstream country receives a benefit *AH* from abatement in the upstream country. Both countries benefit.

Joint cost minimization is represented by *C* in Fig. 12-3, at the tangential point of the utility transformation line and the cost reduction function. Cost minimization is optimal under side payments for a simple reason. It maximizes the cake generated by cooperation in a first step. This "largest-sized" cake can then, in a second step, be distributed amongst the parties.

The Bargaining Approach to Transfrontier Pollution

While the use of side payments in a cooperative solution uniquely determines the abatement efforts of the parties to an agreement (point *C* in Fig. 12-3), the distribution of gains remains only vaguely determined (between *D* and *E*). This nonuniqueness can be resolved by applying particular cooperative solution concepts or by investigating the negotiation process which brings about cooperation. Whatever the solution concept or the particular bargaining situation, any solution to the cooperation problem is constrained by the opportunities of the parties. In terms of Fig. 12-3, these outside opportunities are represented by a recourse to noncooperative behavior in *A*. These outside opportunities are represented in the solution space to the distribution problem by points *D* and *E* which act as threat points in the negotiations between the two countries. The voluntary nature of international environmental agreements guarantees that the solution will be located somewhere on or in between these limiting points of the bargaining solution.

In the bargaining process between autonomous countries, we meet all the problems of environmental policy "in nuce". The environmental media are used as common property resources, consequently the downwind region has no property title to force in the polluting area to abate pollutants; it is not possible to exclude the polluting area from using the environment as a receptacle of waste. The polluting area can behave as a free rider. Without clearly defined property rights, both countries have to determine the tolerable level of pollution in a bargaining process.

In a scenario with a one-directional spillover and in which the upwind country uses the environment as a free good bargaining implies that both countries can only benefit if the pollutee compensates the polluter to reduce pollution in the upwind country (victim-pays principle). Thus, a side payment is necessary. When bargaining costs are neglected, a solution of the game according to Eqs. 12.8 and 12.9 can be found. This bargaining result represents a Coase solution (1960) and a Nash solution (1950) in a cooperative game.

A Nash equilibrium requires that the solution cannot be improved to the advantage of both regions. This implies individual rationality, i.e., the solution must be at least as favorable as the initial situation for each participant. When spillovers are multi-directional, each region has a threat potential irrespective of compensation.

The bargaining situation is characterized by information asymmetries. In the bargaining process, the polluter will exaggerate the costs of pollution abatement in order to reduce the demands of the other country. Similarly, it is expected that the victim will exaggerate the extent of the incurred damages, in order to maximize the assessment of corrective measures needed. In order to avoid this deliberate falsification of information about the damages and costs of the respective abatement, the reciprocal-compensation principle has been proposed (OECD 1973). It has been suggested that an international fund be established to which the polluting country would pay according to its assessment of the damages and the victimized land would pay according to its assessment of the costs of abatement. This approach is designed to guarantee that the factors determining the emission tax are set as realistically as possible. The funds collected from the two parties would then be redistributed to them for the implementation of the environmental-protection measures. It is essential that the countries do not know the rate by which the tax receipts will be redistributed because this information would distort their estimates of the costs and damages.

Policy Instruments for Transfrontier Pollution

The solution to the transfrontier pollution problem requires some commitment of national governments to an international agreement. This commitment may include ceding national sovereignty in the area of environmental policy to an international agency, cost-sharing rules, agreeing on diffusion norms or uniform reductions in national emissions. In the sense of a causal therapy, a solution should explicitly address the quantities transmitted, i.e., $T(E^i)$ in Eq. 12.1. Practical solutions may affect the quantities transmitted only in an indirect way.

Transfrontier Agency

In national environmental-quality management, water quality is often controlled through the establishment of water-management authorities. It is conceivable that similar cooperatives might be formed to control the quality of transfrontier environmental systems such as the Rhine. A precondition for such a procedure is that the transboundary environmental medium can be clearly delineated. Nations could surrender a part of their sovereign rights concerning the environment to an international environmental agency which could tax emissions and thereby control transfrontier environmental quality. The introduction of a tax would create an incentive (for instance, for the upstream polluter) to reduce the emission of pollutants. If countries could agree on a tax, the national environmental agency could set a supplementary tax on emissions within its own borders. However, it is politically unrealistic since nations are not willing to relinquish their sovereignty in this policy area.

Cost Sharing

In such a transfrontier agency, the costs of pollution abatement could be shared by the countries involved. The costs of attaining and maintaining an acceptable level of quality in the transfrontier environmental medium would be added and distributed among the countries according to a set rate. Once again, many problems arise with this proposal. Since costs are determined by the desired level of environmental quality, how much environmental quality should be strived for? By what criteria can abatement costs be attributed to different countries? (See reciprocal compensation procedure.)

A transfrontier agency defined according to the boundaries of a river system should be clearly distinguished from an international agency controlling emissions in the two countries in general. Reducing the general level of emissions in a two-country system only affects transfrontier pollution indirectly and does not solve the basic reason of distortion. By cutting the level of pollution in the country of origin, the externality is reduced in importance, but it continues to exist.

Transferable Discharge Permits

If a transfrontier environmental system can be clearly delineated, marketable discharge systems may be used for the transfrontier system. It then can be left to the market to find the price for emissions. In most cases, however, the approach of marketable discharge permits requires an explicit account of diffusion in order to determine the price of a unit of pollutants at different points in space.

Using transferable discharge permits for the two-country system and thus limiting the total quantity of emissions in two countries is not the appropriate approach to solve the transfrontier pollution issue because it only reduces the general level of pollution in the two-country system, but does not solve the transfrontier distortion. The same argument applies to uniform emission reductions in all countries by a given percentage.

Transfrontier Diffusion Norms

A transfrontier diffusion norm defines the ambient level of pollution of an environmental medium at the border, for instance of a tributary to a river or of air quality at the border. Such diffusion norms have been used in national water management.

A transfrontier diffusion norm allows a decentralized approach to environmental policy in the countries involved. The upstream or upwind country having agreed on a diffusion norm, probably not without a side payment, will internalize the costs of transfrontier pollution to the individual polluters. In such an approach, it can be left to the individual countries by which policy instruments they make sure that the diffusion norm is not violated, and emission tax sales may very well differ between countries. Transfrontier diffusion norms could be instrumental in implementing the polluter-pays principle for the individual polluter, albeit not for the polluting country possibly receiving a side payment.

International Liability Rules

Making countries liable for the damages caused by transfrontier pollution would also permit decentralizing environmental policy among countries. The upstream or upwind country then would anticipate the compensation it would have to pay. This would imply an internalization of environmental costs arising in the downstream country.

Liability rules, however, imply high transaction costs, more specifically time-consuming debates in the international court system. Consequently, liability rules do not represent a dominant solution to transfrontier pollution.

Positive International Spillovers: The Equatorial Rain Forest

Whereas in the case of transfrontier pollution we have negative externalities between countries, there are also positive spillovers. A case in point is the equatorial rain forest. The equatorial rain forest in Brazil and in other countries has a positive value in absorbing CO_2, producing oxygen, and allowing biodiversity. Cutting down the rain forest would represent a negative externality to other countries (Barbier and Burgess 2001).

Similarly, as side payments are required in a solution to reduce transfrontier pollution, one can argue for side payments to the countries with a rain forest to induce them not to destroy it. For the bargaining, however, one difference with the case of transfrontier pollution must be stressed. It might very well be that it is in the long-run interest of the rain forest country to maintain the forest for its own advantages including tourism in the future and that the country has not been aware of its own interests. A major issue is monitoring and enforcement. An international agreement on the protection of the rain forest can be interpreted as a principal-agent problem where the international community is the principal and the rain forest country is the agent. It is difficult for the international community to monitor whether the rain forest country plays by the rules agreed upon, for instance when it receives transfers in order to protect the rain forest.

Biodiversity

Biodiversity is the richness of species of animals and plants in the ecosystem. It is a good or a resource with strong positive externalities: it enhances the productivity of the ecosystem, it represents an insurance, for instance by having a pool of plants being resistant to a virus, it is a source of genetic knowledge, and "keystone species" are crucial in defining the property of complex ecosystems and ecoservices; their removal would affect these systems severely (Heal 1999; Deke 2007). Biodiversity loss has been measured through species extinctions and proxies such as loss of habitat. In recent years, environmental analysts have measured significant declines in biodiversity. According to the World Wildlife Foundation (2002), global biodiversity has decreased by one-third since 1970.

The valuation of biodiversity varies with these different functions. Other more specific, but related value categories may be distinguished, such as genetic diversity and species diversity, natural area and landscape diversity, ecosystem functions, and the existence value (Nunes et al. 2001). For some of the uses of biodiversity, private property rights can be established, for instance for the role of biodiversity to enhance the productivity of natural systems such as agricultural land. The price for a unit of land then would implicitly contain the value of the ecosystem that exists on this piece of land. Another example related to land (or water) are bioprospecting rights. In these cases, the competing use of land can be made explicit and the willingness to pay can be expressed by markets. New intellectual property rights are another recent development, for instance crop developers patenting genes or pharmaceutical firms patenting natural substances for biomedicine. Such rights establish incentives to preserve certain plants if they provide the necessary input for the marketable product.

However, at a given moment of time, not all potential applications of genes and substances can be known. Thus, property rights and markets cannot be established for all potential future uses. There is simply no actual demand for some of these ecoservices. Consequently, biodiversity cannot be preserved by markets alone. An alternative approach becomes necessary. The task is to determine the existence or option value for ecosystems and then to find institutional approaches to preserve them. A possible avenue is to define an ecosystem that is to be preserved in the hope that this system contains a sufficient number of species that may be of value in the future. This is the policy of spatial separation. Countries who have such ecosystems such as the rain forest may be induced to preserve them by international compensation.

International agreements to save specific species such as the whale is another approach. To date, there have been two major international agreements that attempt to deal with biodiversity loss, though both regulate the issue as a legal matter without recourse to economic instruments. The first is the Convention on International Trade in Endangered Species of Flora and Fauna (CITES), which entered into force in 1975. CITES was conceived as an international agreement to prevent the over-exploitation of species, and 164 nations are signatory to it. It classifies species in three categories, allowing export permits for two types and regulating completely the trade in the most endangered type (Finus 2003). To date, no species listed on CITES has become extinct. The second treaty, the United Nations International Treaty on Plant Genetic Resources for Food and Agriculture, has entered into force on June 29, 2004. The Treaty institutes a multilateral system of facilitated access and benefits-sharing for the crops and forages most important for food security. Scientists, international research centers, and plant breeders from public and private organizations benefit from enhanced access to genetic biodiversity. The multilateral system also ensures the fair sharing of benefits derived from the use of genetic resources, in particular for farmers in developing countries that have for centuries contributed to the conservation of genetic resources.

13 Global Environmental Media

Global environmental media are jointly used as a public good by the world as a whole. Diffusion processes are not too important. Examples are the ozone layer and the global warming of the atmosphere. Instead of the diffusion function 12.1, Eq. 12.2 holds defining an international public good.

Global environmental media can be interpreted as open access resources, as a commons with no scarcity price being charged for their use. In principle, each country can take the free-rider position, hoping that the other countries will care for the public good. In addition to the free-rider position other features complicate the solution to the problem:

- Countries or their people may have different preferences with respect to global environmental media and they may have different risk attitudes.
- Even assuming identical preferences and risk attitudes, income per head varies considerably among the countries of the world; this implies a different evaluation of the global environment.
- Although global environmental problems can be interpreted as a public good for mankind, countries may be affected differently if the quality of the public good changes. This indicates that in spite of Samuelson's definition (1954) that the public good "is used in equal amounts by all" the user intensity varies among countries. For instance, global warming and the resulting melting of the ice caps would negatively affect the low lands of the earth such as Bangladesh and the Netherlands.

Global Warming

The overwhelming majority of natural scientists takes the position that CO_2 emissions and other man-made greenhouse gases influence the world's climate. The hockey stick chart of warming in the northern hemisphere since the year 1000 indicates that the global surface temperature has increased in the second half of the twentieth century (Intergovernmental Panel on Climate Change 2001). The temperature of the earth is in equilibrium if it radiates back into space the same amount of energy that it receives from it (the sun), actually 340 watts per square meter (w/m^2). About 100 w/m^2 is reflected back into the atmosphere by clouds so that 240 w/m^2 gets to the Earth's surface. The Earth's surface re-radiates some of the energy which then is trapped by greenhouse gases – water vapor, carbon dioxide (CO_2), methane, and ozone so that about 180 w/m^2 are re-radiated back to the Earth. The climate is sustainable if the Earth emits (240 + 180) = 420 w/m^2. This is the case with a mean temperature of 15° Celsius. With a rising concentration of greenhouse gases, more energy is trapped so that energy radiated to the space is below its equilibrium value.

The carbon cycle has been extensively researched (NASA Earth Observatory Website 2007). Here stocks and flows have to be distinguished. The following values for carbon stocks (carbon dioxide) are given for different environmental media: atmosphere 750 giga tonnes, surface oceans 1,020 giga tonnes, soils 1,580 giga tonnes, and deep oceans 38,100 giga tonnes. With respect to flows, 121 giga tonnes of carbon per year flow from the atmosphere to vegetation and the soil while about the same volume moves in the opposite direction. Carbon flows between the atmosphere and the oceans amount to about 90 giga tonnes, with about the same volume flowing in the opposite direction, also netting out. Man-made greenhouse gases are estimated at 7.1 giga tonnes per year of which 3.2 giga tonnes remain in the atmosphere representing a net addition to the stock of carbon (athropogenic forcing).

Carbon concentration has increased from a pre-industrial value of about 280 parts per million (ppm) to 379 ppm in 2005 (see fourth IPPC report, p. 2). For 400,000 years, CO_2 concentrations fluctuated between 180 and 289 ppm per volume. As a consequence, the world's climate has changed. Continued greenhouse gas emissions at or above current rates would cause further warming. Even if the impact of an increased concentration were not certain, the precautionary principle requires to undertake measures to reduce the emissions of greenhouse gases.

The Noncooperative Solution to Global Media

If an institutional arrangement for global environmental media is sought, two questions arise: (1) Can an agreement be reached? (2) Will the countries stick to the agreement once the agreement is in place? In order to discuss these questions we first analyze the properties of the noncooperative and of the cooperative solution.

In contrast to the transfrontier problem, the damage for a specific country I now depends on reductions of emissions in countries i and j, $D^i(S_o^i+S_o^j-S_r^i-S_r^j)$ whereas costs of abatement are country specific $C^i(S_r^i)$.

In the noncooperative setting each country minimizes its total cost taking abatement in the other countries as given[1]

$$\text{Min } D^i(S_o^i+S_o^j-S_r^i-S_r^j)+C_r^i(S_r^i) \tag{13.1}$$

[1] Compare Hoel (1991).

yielding the optimality conditions for the optimal abatement levels $\hat{S}_r^1$ and $\hat{S}_r^2$

$$-\frac{dD^1}{dS_r^1}(S_o^1+S_o^2-\hat{S}_r^1-S_r^2)=\frac{dC^1}{dS_r^1}(\hat{S}_r^1) \tag{13.2}$$

$$-\frac{dD^2}{dS_r^2}(S_o^1+S_o^2-S_r^1-\hat{S}_r^2)=\frac{dC^2}{dS_r^2}(\hat{S}_r^2) \tag{13.3}$$

In the noncooperative solution of the Nash game, each country abates pollutants up to the point where its marginal benefit is equal to its cost of abatement. The optimal solution of the individual country takes the emission level in the other country as given. It is assumed that both countries take a decision simultaneously. In Fig. 13-1 the optimal points of the noncooperative solution are illustrated by A^1 and A^2 respectively. In Fig. 13-1, OS_o^1 is the quantity of emissions contributed to the global public good by country 1 if no abatement measures are introduced; likewise OS_o^2 for country 2. OS_o is the total quantity of emissions of both countries. Abatement in the noncooperative solution by country 1 (S_o^1D) and country 2 (S_o^2E) add up to S_oA.

Equations 13.2 and 13.3 define the reaction functions $R^1(S_r^2)$ and $R^2(S_r^1)$ of both countries. The reaction function is the set of the minima of the indifference curves which are to be interpreted as curves of equal total costs $\bar{\alpha}^1 = D^1(S_o^1+S_o^2-S_r^1-S_r^2)+C^1(S_r^1)$. For country 1, the curve of equal total costs has the property

$$\left.\frac{dS_r^2}{dS_r^1}\right|_{\bar{\alpha}}=\left(-\frac{dD^1}{dS_r^1}-\frac{dC^1}{dS_r^1}\right)\Big/\frac{dD^1}{dS_r^2} \tag{13.4}$$

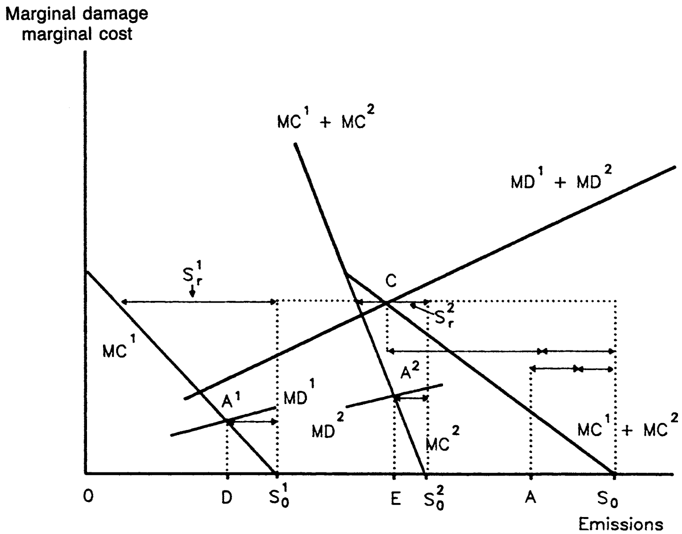

Fig. 13-1. Global environmental media

with $dD/S_r < 0$ and $dC/dS_r > 0$. The minimum of the equal cost curve is reached for a quantity of pollutants abated for which the marginal cost of abatement is equal to the marginal damage of pollutants in country 1 (point X in Fig. 13-2). If less pollutants than at X are reduced in country 1, marginal abatement costs are smaller, but marginal damage is higher. Total costs are higher; thus, the equal cost curve requires that more pollutants are reduced in country 2. Only then can costs in country 1 remain equal. If more pollutants could be abated (to the right of point X), marginal abatement costs would be too high whereas marginal damage would be too low. As a net effect, constant costs are only possible, if more pollutants are reduced in the upstream country. The curve of constant cost must have the property shown in Fig 13-2. In a similar way, the reaction function of country 2 can be developed.

The Cooperative Solution to Global Media

As in transfrontier pollution, the noncooperative solution can be improved. This is indicated by the lense formed by the indifference curves I^1 and I^2 in Fig. 13-3. The frame of reference from which an improvement is possible is given by the indifference levels of the noncooperative solution. Within the lense, there is room for improvement for at least one of the countries.

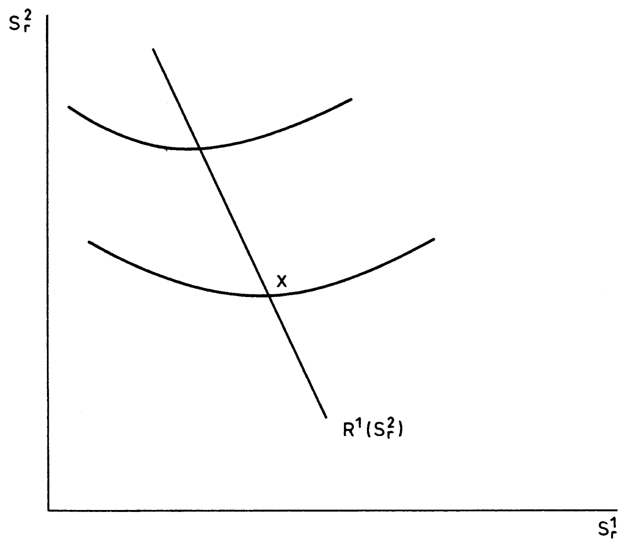

Fig. 13-2. Curves of constant total costs and reaction function

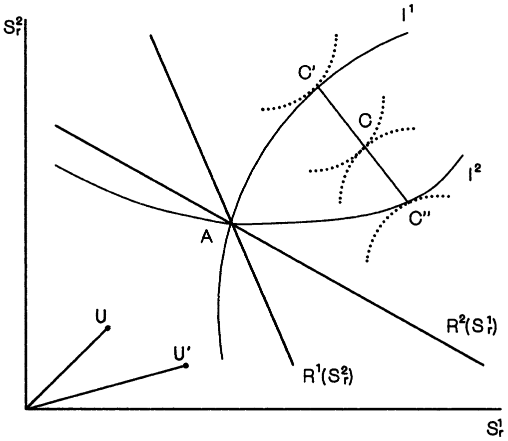

Fig. 13-3. Noncooperative solution for global environmental media

In a cooperative solution, side payments allow to reach a more efficient solution. In a joint optimization problem, total costs for both countries are minimized. The problem is stated as follows

$$\text{Min } D^1(S_o^1+S_o^2-S_r^1-S_r^2)+D^2(S_o^1+S_o^2-S_r^1-S_r^2)+C^1(S_r^1)+C^2(S_r^2) \quad (13.5)$$

The optimal solution requires[2] for the optimal levels of S_r^{1*} and S_r^{2*}

$$-\frac{dD^1}{dS_r^1}(\cdot) - \frac{dD^2}{dS_r^2}(\cdot) = \frac{dC^1}{dS_r^1}(\cdot) = \frac{dC^2}{dS_r^2}(\cdot) \quad (13.6)$$

[2] The optimality conditions are

$$-\frac{dD^1}{dS_r^1}(S_o^1+S_o^2-S_r^{1*}-S_r^{2*})-\frac{dD^2}{dS_r^1}(S_o^1+S_o^2-S_r^{1*}-S_r^{2*})=\frac{dC^1}{dS_r}(S_r^{1*})$$

$$-\frac{dD^1}{dS_r^2}(S_o^1+S_o^2-S_r^{1*}-S_r^{2*})-\frac{dD^2}{dS_r^2}(S_o^1+S_o^2-S_r^{1*}-S_r^{2*})=\frac{dC^2}{dS_r}(S_r^{2*})$$

From

$$\frac{dD^1}{dS_r^1}=\frac{dD^1}{dS_r^2} \quad \text{and} \quad \frac{dD^2}{dS_r^1}=\frac{dD^2}{dS_r^2}$$ follows Eq. 13-6.

Joint maximization requires that the aggregated prevented marginal damage is equal to the marginal cost of abatement in country 1 which again must be equal to the marginal cost of abatement in country 2. The equality of the marginal cost of abatement in both countries is due to the fact that emissions are homogenous in both countries. It does not matter where pollutants are abated. Thus, equalizing the marginal abatement costs implies efficiency in abatement. Pollutants are reduced with a minimum of total resource costs. The condition that the sum of marginal prevented damage is equal to the marginal cost of abatement is Samuelson's summation condition for the optimal provision of public goods (compare Eq. 5.7). This implies the vertical addition of the willingness to pay. For joint maximization the optimal supply is given by point C in Fig. 13-1 where the (vertically) aggregated willingness to pay, i.e., the aggregated marginal prevented damage ($MD^1 + MD^2$), and the (horizontally) aggregated cost function ($MC^1 + MC^2$) intersect.

More formally, the cooperative solution can be modelled as both countries jointly maximizing the additional joint benefit relative to the noncooperative solution (Hoel 1991). The minimizing problem then is given by both countries maximizing the reduction benefits that they can obtain relative to the noncooperative solution.

$$\text{Max } [-D^1(S_o^1+S_o^2-S_r^1-S_r^2)-C^1+X^1]+[-D^2(S_o^1+S_o^2-S_r^1-S_r^2) -C^2+X^2] \tag{13.7}$$

where X^i are the total costs imposed by the noncooperative solution

$$X^i = D^i(S_o^1+S_o^2-\hat{S}_r^1-\hat{S}_r^2)+C^i(\hat{S}_r^i) \tag{13.8}$$

with $\hat{S}_r^i$ representing the optimal solution in the noncooperative equilibrium.

The solution of the maximization problem gives the reduction of costs that can be obtained in a cooperative solution, i.e., the payoff.

In Fig. 13-3, the cooperative solution lies on a line $C'CC''$ where the indifference curves of the two countries are tangent to each other. Point C is a possible Pareto-optimal solution. Any point in the lense I^1–I^2 represents an improvement relative to point A. The set of points in the lense is given by the points on and under the curve $C'CC''$ in Fig. 13-4. The curve $C'CC''$ denotes possible improvements in the welfare of both countries without side payments.

Although the cooperative solution, for instance C in Fig. 13-3, represents an improvement for both countries, the improvement may not be reached. This is the prisoner's dilemma in which no joint action is taken even though both countries could be the better off. Especially, if many countries are involved, a country can take the free-rider position.

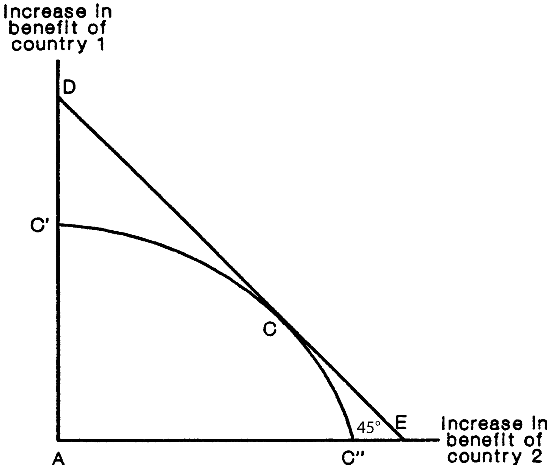

Fig. 13-4. Cooperative solution and side payments

Side Payments and Global Goods

Let us now distinguish the question whether an agreement can be reached from the question whether an agreement can be sustained (Barrett 1992). If two countries are considered and if both countries are identical, it should not be too difficult to reach a solution. In this case, a uniform reduction is efficient.

If countries differ, side payments can be instrumental in reaching a cooperative solution. Side payments are represented by a 45° line *DE* in Fig. 13-4. Consider a distribution of benefits illustrated by point *C* in Fig. 13-4 which corresponds to a vector of reduction (S_r^1, S_r^2) as denoted by point *C* in Fig. 13-3. Any point of the line *DE* can be obtained by side payments. In our context of minimizing total costs, side payments are to be interpreted as reducing a country's total cost. Thus, side payments enter countries' utility functions by a unitary marginal utility. *DE* gives the side payments which sustain the cooperative solution 13-6. Figure 13-4 depicting the cooperative solution in the case of a global good can be compared with the cooperative solution in the case of transfrontier pollution (Fig. 12-3).

Countries can differ in their preference functions and in their abatement cost functions. Then the lense of mutual advantage in Fig. 13-3 and of benefits in Fig. 13-4 may be biased in favor of one country. In Fig. 13-5 it has been assumed that country 1 has a very strong preference for global environmental quality (given identical abatement cost curves between countries) or very low abatement costs (given identical preferences). Consider again a distribution of benefits *C* without side payments. In such a situation country 1 would have relatively high benefits, and country 2 may not be willing to undertake its part of abatement because it feels that the increases of the countries' benefits, i.e., the countries' bargaining gains, are distributed unequally. By a side payment

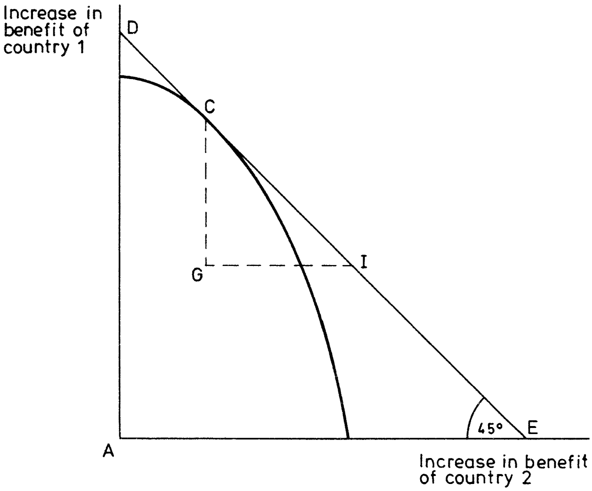

Fig. 13-5. Side payments

CG = *CI* of country 1 to country 2, point I may be reached. Country 1 gives part of its gain to country 2. Relative to the noncooperative solution A, both countries gain.

Controlling the Free Rider

Assume an agreement has been reached. Then the issue arises whether and to what extent such an agreement will be upheld. Although countries can improve their benefit relative to the noncooperative solution, each country has an incentive to behave as a free rider, i.e., enjoying the benefits of a better global environmental quality without carrying the costs for it by simply disregarding the agreement. This is the prisoner's dilemma. The countries are characterized by noncooperative behavior and they are unable to find a cooperative solution. Upholding an agreement can become problematic because countries have different economic and environmental conditions with respect to their stage of development and because they have different preferences vis-à-vis environmental degradation, diverging willingness to pay, and different attitudes and commitments to multilateral approaches. Consequently, countries are tempted to play the game of enjoying the public good without carrying the cost for it.

Sanctions

Sanctions may exist, if an international agreement is dominated by a political hegemon (as the US in the case of the GATT in the 1950s and the 1960s). In such a setting, countries are linked to each other by a variety of interdependencies, and even if the free-rider position in environmental issues would be in the interest of a country, its behavior is controlled by the hegemon in other fields of interest. Alternatively, free-rider behavior may be reduced if the agreement can be interpreted as a repeated game played over many periods. Then, the benefit that a free rider can reap in a specific period, must be balanced by potential costs that he/she will incur from the behavior of the other players in the future. Reputation matters, and this may induce a potential free rider to adhere to the agreement. Reputation is especially relevant, if not only one layer of interdependencies exists (such as the global environmental media) but also other interdependencies. Then other fields may provide sanctions against free-rider behavior in pollutants.

Self-enforcing Contracts

In contrast to a national setting, where sanctions exist, sanctions are usually lacking internationally and international agreements cannot be enforced. As a solution the idea of a self-enforcing contract has been developed (Barrett 1994a, 2005). The incentive structure of a multilateral arrangement must be such that it is in the interest of a country to behave as every country would like it to behave. One approach is that countries agree to sanctions and bind themselves in this way. Another aspect consists in creating credible sanctions for the members of the group for the case that a member deviates. Barrett (1992) discusses a mechanism by which countries link their abatement activity to the other countries. If a country reduces its abatement activity not sticking to the agreement any more, other countries lower their emission reduction as well, thus inflicting a damage on the deviating country. Instead of such a negative mechanism of linking policy instruments which may be destabilizing, a positive mechanism can be introduced: A country will abate more if another country abates more. This is to some extent similar to bound tariffs. Countries may agree on a minimum participation level. This may make it more attractive for countries to join the agreement. Countries may agree on a fine system so that the polluter who deviates from agreed upon standards must pay a fine. The countries joining the agreement may commit themselves by an initial lump sum investment in the project. The capital can be used to finance side payments as an incentive to abate. All this should help in preventing the potential free rider from taking the free-rider position. The more demanding an agreement is, the fewer willing participants it will find. A whole array of proposals to stabilize international environmental institutional arrangements can be found in Heister (1997).

Coalitions

In contrast to a wide multilateral agreement with many states, countries with a special interest in environmental problems may form a coalition. Then the issue arises whether an agreement can be made attractive for potential members, i.e., whether each member enjoys a benefit in order to overcome the incentive of free riding. Then a small coalition may eventually extend to a comprehensive international agreement. An example is the Montreal Protocol, originally starting out with 26 members and now extending to 180. An example from another area is the European Union which over fifty years succeeded in attracting potential members. Thus, conditions can exist in which it is interesting for a potential member to opt into the agreement instead of opting out, i.e., remaining outside (Heal 1992). Several reasons can be put forward: First, consider the case where abatement functions are characterized by fixed costs. If a country reduces pollutants unilaterally, it is likely that the costs of abatement are larger than the benefit for this country, unless the country is very large. Thus, a country may be able to reduce the role of its fixed costs, if it joins the club. Second, other complementarities between the abatement functions, i.e., positive externalities, also are an incentive to become part of a group. Positive spillovers may exist for instance through technology transfer. Third, the interdependencies of countries may exist in other fields as well influencing the reputation in the long run. Fourth, countries may introduce a mechanism which effectively creates a sanction. Thus, increasing emissions when a free rider raises its emissions establishes a sanction (see above). Reducing emissions by a certain percentage when a new country joins an agreement represents a positive externality making a coalition attractive.

Especially, if no hegemon exists, countries of more or less equal size may form a coalition in order to exploit complementarities. Heal (1992) defines a minimum critical coalition as the smallest coalition with the property that all members will gain from an abatement agreement. Without side payments, benefits must at least be equal to costs for each country taken separately. With side payments benefits plus side payments must be equal to costs. Thus a net loss of a specific country can be compensated by a side payment. Apparently, side payments allow to enlarge a coalition. Conditions for coalitions are more fully analyzed in Finus (2003), including the issue of how to enforce an agreement.

The Unilateral First Mover

Together with a few other countries, Germany has adopted the first mover strategy in environmental protection. It has gone first on many environmental prospects, granting some exceptions to its energy-intensive and pollution-intensive industries. In the case of global environmental goods, the problem of this approach consists not only in losing competitiveness, but also in firms migrating to other countries. They then may produce more pollutants than before, because environmental policy at the new location is laxer. As a result, global pollution may even increase. This is called the leakage effect (Rauscher 1997). This argument has some similarity to the race to the bottom problem. Some of the reasons given why there are bounds to a race to the bottom apply here as well.

Uniform Reduction

A solution to global environmental issues consists in agreeing on a limit for the total quantity of emissions and then allocating the tolerable level of emissions to the individual countries. In contrast to the transfrontier pollution problem, now the total quantity of emissions is the decisive variable in the sense of a causal therapy.

Allocating the tolerable quantity of worldwide emissions by a uniform reduction rate of x percent in each country is not efficient, unless countries are completely identical. Some countries may be able to reduce emissions at much lower costs. In Fig. 13-3, the ray OU from the origin represents a uniform emission strategy under the assumption that the initial level of pollution is equal in both countries. If the initial level of pollution is higher in country 1, i.e., $S_o^1 > S_o^2$ and if a proportional reduction is required, country 1 must abate more than country 2 (point U'). If countries differ in their preferences and in their abatement costs, it is only by chance that a point like U' guarantees cost levels as low as the noncooperative solution A or as the cooperative solution on the line $C'CC''$. It should also be noted that uniform reduction rates do not protect against reneging and thus endanger the stability of the institutional arrangement.

A Workable System of Transferable Discharge Permits

Transferable discharge permits prevent the inefficiency of uniform reduction schemes. They make sure that the reduction of emissions occurs in the more efficient countries. This means that the costs of environmental protection are minimized for a given target level of environmental protection. Moreover, global environmental media are especially suited for transferable discharge permits because diffusion problems ("hot spots") are not relevant. In Fig. 13-1, point C denotes the global environmental quality to be attained. A market for emission rights will establish the price corresponding to point C.

Such a system of discharge permits can be interpreted as an institutional implementation of a cooperative solution. The following problems have to be solved: (i) the tolerable level of pollutants ambient in the global medium (or the total tolerable quantity of emissions) has to be determined and (ii) it has to be specified how discharge permits are to be allocated to different countries, both initially and during the operation of the system (Grubb and Sebenius 1992; Tietenberg 2003).

The allocation of discharge permits is irrelevant for the efficiency of the system once the system is established. If permits are tradable, efficiency will follow. The allocation is relevant, however, for the acceptability and for the sustainability of the system, i.e., for the question whether a cooperative solution can be found and upheld. The theoretical analysis suggests that some side payments may be necessary to get acceptance for an international permit system.

Different criteria have been discussed for the allocation of permits (Grubb and Sebenius 1992; Tietenberg 2003). An allocation according to historical emissions or "natural debt" would use accumulated emissions of a country as a criterion. These would be interpreted as an indicator how intensively a country has used the global environment in the past. Countries with more accumulated debt would obtain fewer discharge permits. This system would benefit the developing countries in such a way that it may not be acceptable to the industrial countries. A land area criterion would be in favor of large not densely populated regions, that already have a large resource base such as Russia. An allocation according to GDP would be in favor of the industrial countries. Finally, permits could be allocated on a per capita basis. Such an allocation may contribute to the stability of a worldwide system of discharge permits. This criterion may be fair, but the per capita allocation has the disadvantage that population growth which is one cause of the problem is rewarded. As a result, a mixed index using population and other criteria may be necessary. With such an allocation giving a strong weight to the per capita criterion, a country like China would receive a large share of global emission rights which it could sell to the other countries. The other countries might also lease the emission rights so that a country like China may use them later. Allocating emission rights on a per capita basis with additional aspects may be a mechanism that contributes to the stability of the institutional arrangement.

Reneging the Contract

Besides the initial allocation, quite a few issues would have to be solved relating to the behavior of the system over time. An important problem is whether the institutional arrangement is sustainable, i.e., whether countries will renege.

The institutional arrangement would need a long duration because global environmental quality and abatement activities for its improvement are long-run problems. At the same time the system should be flexible enough to include additional countries, new sources of emissions as well as new sinks. Discharge permits should not last indefinitely, because the system then will be too rigid. For instance, future governments may be discontented with the sale of permits by their predecessors, and they may walk away from the contract. Indefinitely valid permits which could not be sold but only leased may also prove to be too rigid to allow a change of the system in the future.

Permit holders have a strong interest to hold a permit for some time, for instance for the period of operation of a facility. They cannot live with the uncertainty not to obtain the permit for the next year. For that reason permits must reflect the lifetime of capital, for instance, in the energy sector allowing a firm to buy a permit when it starts a new facility. A possible solution seems to be a lifetime of the permit of two to three decades which means that the price of a permit will fall over its lifetime. In order to start a system of permits, a mix of permits with different lifetimes can be introduced.

An International Order for the Global Environment

When international public goods are involved and when nations can behave as a free rider or strategically, an institutional arrangement is called for. Such an order defines the rules for the behavior in individual countries. Each country has to commit itself to these rules. In analytical structure, the problem is similar to the rules for multilateral trade. This institutional arrangement is intended to prevent strategic behavior of individual countries to improve their national benefit by creating losses or costs somewhere else.

International Agreements. International environmental agreements are an efficient (first-best) way to address international environmental problems, because international cooperation policies can, in principle, be designed as if the world were a single country and as if the polluter-pays principle were applied worldwide.

However, such agreements may in practice be difficult to be reached and sustained. First, they are subject to free riding, because global environmental media are public goods. Second, some countries may attach lower priority to solving a global environmental problem than others, because of differences in preferences and attitudes toward risk or disagreement over the scientific evidence. Third, differences in per capita income generate different valuations of global environment quality, even where preferences and risk attitudes are identical. Fourth, global environmental problems such as global warming may affect countries differently, so that the public good in question is not a pure public good. Fifth, countries may disagree with respect to the distribution of abatement costs.

Under these conditions, countries will be tempted to behave strategically. Negative and positive inducements (stick and carrot) may conceivably provide a mechanism for prodding nations toward cooperative behavior and to implement international environmental agreements. But even with sticks and carrots, cooperative solutions for global environmental problems are extremely difficult to achieve.

Moreover, the stability of the institutional arrangement poses a similar problem in the trade policy and in the environmental case. Over time, the national interest of a country may change; it may renege on the institutional arrangement which then becomes unstable. Like any international agreement, institutional arrangements must therefore contain mechanisms that make them stable and prevent reneging.[3]

The world as a whole can benefit from a cooperative solution, both in the trade and in the environmental case. Some impetus is necessary to brake the

[3] On the stability of investment contracts, compare Thomas and Worrall (1990), Mohr (1990a).

deadlock of a prisoner's dilemma, for instance, a hegemon in the trade case or, possibly, the pace setting of a country moving first in environmental policy.

Trade Sanctions. Sanctions such as trade restrictions have been proposed as a way of moving nations toward cooperative behavior. Trade sanctions make cooperative nations better off while making uncooperative nations worse off, in part by producing terms of trade gains for the former that exceed losses in trade volume brought about by compliance with an international agreement on the environment.

Trade sanctions have several disadvantages, however. Their credibility as a penalty mechanism is reduced if non-signatories or defectors are likely to retaliate in response to sanctions. Moreover, trade sanctions may open a Pandora's Box of protectionism, with all the attendant uncertainties pertaining to the international division of labor. In the long run, reduced gains from specialization and trade may be greater than the initial gains from improvements in global environmental quality (Rauscher 1996, p. 326).

Trade sanctions may cut resource transfer to low income developing countries, reducing economic growth there and therewith the long-run potential for improved environmental quality. Sanctions may thus increase rather than reduce environmental degradation over time, for the well-known reason that income levels and the demand for environmental quality are highly correlated.

Finally, the impact of trade sanctions may be ambiguous (Hufbauer et al. 1990) and hence their use problematic.

Although in a game-theoretic context, sanctions can be modeled so as to induce cooperative behavior in environmental issues, they may destabilize the institutional order for trade and investment. Thus, sanctions may stabilize one order – the rule system for the environment – and destabilize the other – the order for trade and investment. From the point of view of institutional arrangements or of "Ordnungspolitik" in the sense of the Freiburg School, an order for one policy area should not be contingent on the institutional arrangement for another policy area because then the overall order will not be stable. There is a hierarchy of order, and interdependence of subsystems of order in the hierarchy is an important aspect of the overall order. Therefore, care must be taken that the order for trade and investment and the order for the environment are independent of each other. In any case, sanctions against an individual country should only be used if applied by an international organization within the framework of an existing international agreement which the country has signed. This implies that a system of sanctions has to be accepted by the countries in advance on a voluntary basis in the sense that countries bind themselves; otherwise sanctions can lead to a degenerating process of intensified international conflicts.

Side Payments. Positive incentives are likely to be more effective than negative ones in the promotion of international environmental agreements. Countries which place high values on global environmental quality can attempt to induce others to abate pollutants by offering compensation. Here, the polluter-pays principle is replaced by the victim-pays principle. Such compensatory payments are a mechanism for ensuring that abatement occurs at the lowest costs.

The prospect of compensation may, however, create moral hazard problems. If a country expects compensatory payments, it may behave strategically in abating less than its national optimum in order to increase the amount of compensation. Cost-sharing and earmarking of compensatory transfers may help to overcome these difficulties. Foreign direct investment in environment-friendly technologies and cross-border investment credits may also help.

Trade Liberalization. Trade liberalization may be particularly effective in inducing countries to participate in international environmental agreements. It is attractive because it improves income growth prospects in many developing countries and thereby lays the foundation for future willingness to pay for higher environmental quality (Maestad 1992, p. 72). Side payments in the form of improved market access are superior to monetary transfers (provided that environmental externalities are appropriately internalized), because trade liberalization is likely to involve positive efficiency effects in addition to its redistributive effects (Maestad 1992, p. 60). Compared with monetary transfers, trade liberalization may also reduce the moral hazard problem.

Termination and Compensation. When voluntary compliance cannot be achieved, questions arise with respect to the global community's right and will to force compliance. Operational criteria need to be developed with respect to forcing countries to discontinue policies which damage the global environment and the extent to which such countries should be compensated. Compensated termination should dominate sanctions.

The Kyoto Protocol and Beyond

The total volume of CO_2 emissions amounts to 24 billion tons (Table 13-1). The US accounts for 24 percent, the European Union (EU-27) for 16 percent, and China for 15 percent. The issue is how these emissions can be reduced. The International Energy Agency (2006) attributes 49 percent of the 2004 CO_2 emissions to the OECD countries, 18 percent to China, 9 percent to Asia (ex China), and 9 percent to Russia.

In the context of the United Nation's Framework Convention on Climate Change the signatories of the Kyoto Protocol (1997) have committed themselves to reduce greenhouse gas emissions. The Protocol lays out national reduction commitments primarily for industrialized countries, taking the 1990 emissions as a starting point. The "commitment period" for the reductions is between 2008 and 2012, allowing for fluctuations to be averaged out. Commitments are 5.2 percent on average for industrialized countries relative to their 1990 emissions. They vary between countries (Table 13-2). The target is minus 7 percent for the United States, minus 12.5 percent for the United Kingdom, and minus 8 percent for the European Union. Germany has committed herself to reducing greenhouse gas emissions by 21 percent. The reason for a reduction target of zero in the case of Russia is seen in the restructuring of the Russian economy after its reorientation to market processes; this is supposed to be sufficient for

CO_2 reduction. The Kyoto Protocol thus lays out legally binding limits on greenhouse gas emissions in industrialized countries, the Annex I countries. China, India, and Brazil do not belong to this group. Countries that pollute less than they have committed to do can trade emission certificates with countries which desire to produce more CO_2 emissions than they are entitled to. Basically the approach used is a cap-and-trade system.

The Kyoto Protocol came into force in February 2005, after it was ratified by Russia in 2004. As of December 2006, the Kyoto Protocol has been ratified by 168 countries plus the European Union, accounting for 62 percent of CO_2 emissions. The US, which was responsible for 17.4 percent of global 1990 carbon dioxide emissions, has not ratified the Protocol; it withdrew from it in 2001. Australia also has not ratified the Kyoto Protocol. In getting the Kyoto process started, a particular procedure was chosen to set the Protocol into force. It was considered as being ratified if at least 55 countries, responsible for at least 55 percent of 1990 CO_2 emissions of Annex I countries, had ratified the Protocol. This procedure was chosen to ease the ratification of the Protocol and to introduce a minimum reduction of emissions.

The first stage of the Protocol expires in 2012; subsequent arrangements are already discussed. With regard to this, negotiations will take place in the

Table 13-1. World[a] CO_2 emissions[b] in 2002

	Emissions	In percent
EU-27	3,865	16.0
France	368	1.5
Germany	850	3.5
Italy	432	1.8
UK	543	2.3
Australia	356	1.5
Canada	516	2.1
Japan	1,202	5.0
Russia	1,431	5.9
S. Korea	445	1.8
USA	5,834	24.2
Brazil	313	1.3
China (incl. Hong Kong)	3,545	14.7
India	1,219	5.1
Mexico	383	1.6
S. Africa	345	1.4
Others	4,654	19.3
World	24,107	100

[a] Excluding Taiwan
[b] In million tons
Source: World Bank, World Development Indicators, onlin

Climate Change Dialogue among the G8 plus 5 (United States, United Kingdom, Canada, France, Germany, Italy, Japan, and Russia as the G8 plus Brazil, China, India, Mexico, and South Africa as the 5) in 2009. An agreement for such negotiations to take place was reached in Washington in 2007. The participants acknowledged the effects of greenhouse gas emissions on climate change and the responsibility of both developed and developing countries to reduce these emissions. A global carbon market for CO_2 emissions is to be established.

Meanwhile, the US has launched a counter agreement to the Kyoto Protocol in 2006, the "Asia-Pacific Partnership on Clean Development and Climate," including Australia, India, Japan, China, South Korea, and the United States, of which only Japan has legal obligations under the Kyoto Protocol. The member countries account for around 50 percent of the world's greenhouse gas emissions. This institutional arrangement does not include a mandatory enforcement mechanism. Emission reduction targets are set individually for the member countries. The intent is described in general terms, i.e., to develop, deploy, and transfer existing and emerging clean technology, meet increased energy needs and explore ways to reduce greenhouse gases without hurting the economies, and seek ways to engage the private sector. The Canadian government has given up meeting its Kyoto requirements and contemplates joining the above agreement. The US does not want to commit itself to Kyoto, since it claims scientific ambiguity about climate change and expects strains on its economy, given that its main future rival, China, does not participate. The US' own proposal includes China as well as India.

The Kyoto approach contains several flexible mechanisms. Emissions can be traded among Annex I countries. Countries that reduce more emissions than agreed upon can sell the emissions credits to other countries. Emission reductions can also be banked. The Joint Implementation Mechanism means that emission reduction credits can be obtained for undertaking emission reduction in projects of another Annex I country. The Clean Development Mechanism applies to projects in developing countries that have no targets under the Kyoto Protocol. The reasoning is that since global warming is a global environmental medium, specific sites of emissions reduction are inconsequential; it is also hoped that joint implementation will encourage the transfer of environmentally sound technology to developing countries.

Table 13-2. National greenhouse gas reduction targets, Kyoto

Country/region	Percent change from 1990 emissions
Australia	+8
European Union	–8
France	0
Germany	–21
United Kingdom	–12.5
Russian Federation	0
United States	–7

EU Emission Trading

The most significant efforts toward implementing the Kyoto Protocol have taken place in Europe. The European Union has committed itself to an overall reduction of 8 percent of 1990 emissions; this goal was ratified in May 2002 by the EU and all its member states. Additionally, the ten new member countries which have joined the EU in 2004 have all ratified the Protocol and have their own reduction targets between 6 and 8 percent. In 2007, the EU has set the target of reducing CO_2 emissions by 20 percent by 2020. It has offered a reduction of 30 percent if other countries would go along.

Emission trading in the EU began in 2005 between member states, each of which has established a national allocation plan. In its first phase 2005–2007, the system covered only CO_2 emissions and was initially located only in the power, oil refining, cement production, iron and steel manufacture, glass, ceramics, and paper and pulp industries. The second period 2008–2012 will include all greenhouse gases but it is not yet settled whether aviation emissions will be covered. There is a window for entrance until 2008, at which point all relevant installations must be included (EU Commission website). Emissions trading will use one ton CO_2 as the allowance currency, and fines per excess unit will be 40 euro until 2007 and 100 euro thereafter. It is estimated that between 12,000 and 15,000 installations will be covered by the emissions trading system.

The initial distribution of allowances, as envisioned in the national allocation plans, is one of the most significant determinants of the effects of emissions trading. The European Commission left it to the member states to allocate their emission rights to the different sources and has offered three different approaches to allocate the rights: the historic approach with emissions of a base year, the forecasting approach, and the least cost approach. In the historical emissions model, companies were given permits at a rate matching their current emissions. The forecasting approach was similar, but corrected for expectations about which sectors will grow or contract in the economy. The least cost approach attempted to equalize abatement costs both within the emissions trading sectors (which will happen in any event) and abatement costs in other sectors, and consequently allocated fewer permits to the trading sectors. The United Kingdom and Ireland used primarily a forecasting approach, while Denmark's national allocation plan was based on historical emissions. In Germany, it was heavily debated how past reduction efforts are to be integrated into this scheme and how the total amount of emissions of these sources relates to other emission sources. The new EU member countries not only have lower abatement costs than Western Europe but also are in many cases already below their Kyoto targets, due to the economic restructuring following the collapse of Communist rule. This enables them to sell excess permits.

Each EU member proposed a national allocation plan to the EU Commission for approval. The national allocation plans must be in line with Kyoto targets. Progressively tightening caps are foreseen for each new period, forcing overall reductions in emissions.

With 764 million tons of CO_2 trade in the first three quarters of 2006, EU emission trading represented about 75 percent of the global carbon market in terms of volume traded (Table 13-3). Carbon exchanges have developed in different locations, for instance EEX in Germany, APX in the United Kingdom, Powernet in France, and CXX in Chicago. Some of these exchanges also trade futures. Moreover, voluntary pools have emerged (e.g., North Pool for Scandinavia).

The starting price per unit allowance was at about 10 euro and reached a first peak in July 2005 just below 30 euro. It broke through the 30-euro benchmark in April 2006 but dropped down to below 20 euro shortly after. In the middle of February 2007, the price even fell below one euro. The reason was an excess supply of allowances from national allocation plans. Another reason is that the allowances expire at the end of 2007 and new permits are required for the next phase. Futures for 2008 demand a higher price. In principle, one can rate the EU emission trading as successful.

Table 13-3. World carbon market 2006[a]

	Volume[b]	Value[c]
Allowances		
EU Emission Trading Scheme	763.9	18.8
New South Wales Greenhouse Gas Abatement Scheme	16.2	0.2
Chicago Climate Exchange	8.25	0.03
UK Emissions Trading Scheme	2.3	0.01
Subtotal	790.65	19.04
Project-based transactions		
Clean Development Mechanism	214.3	2.3
Joint Implementation	11.9	0.09
Other compliance	7.9	0.06
Subtotal	234.1	2.45
Total	1,024.75	21.49

[a] First three quarters
[b] In million tons
[c] In billion US$
Source: International Emissions Trading Association (IETA) (2006)

14 Regional Aspects of Environmental Allocation

In contrast to global or international environmental systems, regional media relate to the spatial subsystems of a nation such as river systems, groundwater systems, or air regions. Regional media may also cut across national political boundaries, as occurs in the upper Rhine Valley where France, Germany, and Switzerland are linked. In this chapter we present a spatial-allocation model for a two-region system where pollutants are transmitted via environmental media from one region to another. The implications of the allocation model are derived and explained. The basic result is that emission taxes have to be differentiated according to regional conditions. The institutional problem of whether environmental allocation should be undertaken by national or regional authorities is discussed. Finally, we look into some practical problems such as interregional equity requirements and the relationship between regional environmental policy and regional planning.

The Problem

What is so special about environmental allocation in a regional setting? We focus on three components of the problem: delineation of environmental regions, interaction among regions, and policy approaches to environmental allocation. These issues introduce factors concerning the problem of environmental allocation that were not considered previously.[1]

Delineation of Regions

The space which a country occupies can be viewed as consisting of different sets of regions; for instance, we may distinguish among economic areas, political entities, and environmental regions which vary with environmental media. A *region* can be defined as a set of spatial points that either are homogeneous with respect to some variable (criterion of homogeneity) or are more intensively interrelated to one another than to other spatial points (criterion of functional interdependence). We may construct economic regions according to sociocultural or historical criteria or by using such economic variables as industrial structure, rates of unemployment, per capita income, or

[1] For a survey of the problem, compare Siebert (1979b, 1979d, 1985).

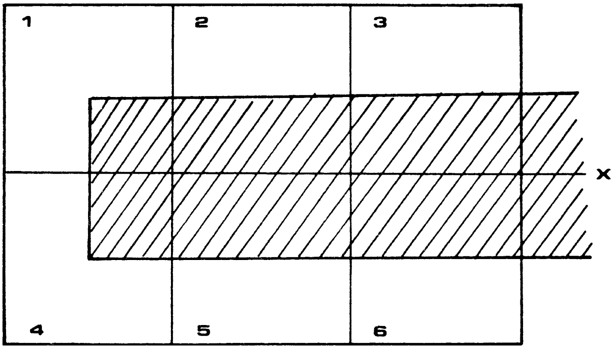

Fig. 14-1. Delineation of regions

intensity of economic exchange via commodity exchange and factor mobility. Correspondingly, environmental regions may be defined by environmental characteristics. For instance, interaction among spatial points through environmental media such as the groundwater system, a river system, or a meteorological system may define an environmental region.

Environmental regions for different media will not be identical. In Fig. 14-1, sections 1 through 6 may denote air regions, and x may indicate a river system. Regions for different environmental media may overlap. Moreover, environmental regions and economic areas are not identical. An economic area may be delineated according to industrial structure (that is, a coal district) or the state of development (depressed area) while an environmental region is defined according to the spatial extent of an environmental system. For instance, in Fig. 14-1, areas 1 through 6 may be interpreted as economic or planning regions, and x may be considered to be an environmental system.

Interactions Among Regions

Environmental regions are interrelated. Environmental disruption in one area will cause repercussions in other areas. Similarly, environmental policy for one region will have an impact on other areas. We may distinguish among the following mechanisms of interaction.

1. Environmental regions are interrelated in that pollution in one area will affect the environmental quality of another region by the interregional diffusion of pollutants to the other areas (interregional spillovers). This problem is similar to the case of international diffusion.

2. Economic regions are interrelated through the mobility of commodities. For instance, a strict environmental policy in one economic region may lead to an increased specialization of less pollution-intensive commodities while another area could specialize in more pollution-intensive commodities. The exchange of goods will affect regional environmental quality.

3. Similarly, factors of production may migrate among regions, leaving those areas where factor prices have been reduced as a result of environmental policy.

4. Residents may migrate among regions owing to differences in environmental quality. Note that residents are not necessarily identical to workers and that environmental quality and wages both determine the mobility of labor. If residents have an influence in the political process, their mobility will affect the target values established for environmental quality.

5. Administrative or planning regions may be interrelated in the sense that the environmental quality in one area is an argument variable in the welfare function (of the inhabitants) of the other region (that is, amenities in one area are esteemed by the inhabitants of another area), either because the other region assigns a value per se to these public goods or because the region uses them during holidays for recreational purposes (temporal mobility of residents). Also, demonstration effects may occur among regions, with environmental quality in one area influencing the achievement levels in other regions.

6. Administrative regions may be interrelated by institutional arrangements such as a grants-in-aid system among regions. Also, the assignment of different types of taxes and expenditures to regions may create an interdependency among regions. This occurs if regions interact in the political process of assessing taxes and allocating expenditures to administrative levels. More unlikely, regions may have to interact in order to determine the volume of expenditures (that is, for interregional public goods) or taxation (financing interregional public goods). In this context, the country's constitution plays an important role. Federal states such as Switzerland or the United States may have institutional arrangements different from those of a central state such as France.

Problems of Regional Allocation

With respect to the interdependency among regions, the following questions of spatial environmental allocation arise:

Should nationally uniform or regionally differentiated environmental policy instruments be used?

Should environmental policy be pursued by national or regional agencies?

Should the desired level of environmental quality be regionally differentiated or nationally uniform?

Can the different types of regions (economic areas, environmental systems) be delineated consistently?

What are the spatial effects of the various environmental instruments, and what relationship exists between regional planning and environmental policy?

Spatial-Allocation Model

For simplifying purposes, a two-region case is considered. We use the same functions as in chapters 3 and 4. Every region has two production functions, two pollution functions, two abatement functions, and a damage function. Subscripts denote sectors; however, superscripts now indicate regions, not individuals as in chapter 4. Furthermore, we assume that the welfare functions are separately formulated for each region; that is, the regional welfare W^j is affected by only the regionally produced commodity Q_i^j and the regional environmental quality U^j:

$$W^j = W^j(Q_1^j, Q_2^j, U^j) \quad j = 1,2 \tag{14.1}$$

This function neglects the interregional interdependence of welfare functions. Residents of region 1 are indifferent to the environmental quality of region 2. For instance, we do not take into account the possibility that region 2 may be the recreation area of region 1 or that residents of one region may care about scenic landscapes in the other area. For simplicity, note that we also assume that output determines regional welfare. This means that there is no interregional exchange of commodities.

In order to explicitly consider the interregional diffusion of pollutants, it is assumed that pollutants are transported from region 2 to region 1 through environmental systems. Let S^{21} denote the quantities of pollutants being transported from region 2 to region 1. Here S^j represents the ambient pollutants in the environment of region j, S_e^j the gross emissions of region j, S_r^j the abated emissions, and S^{aj} the regional assimilative capacity, which is given exogenously. Then pollutants in region 1 are defined as[2]

$$S^1 = S_e^1 + S^{21} - S_r^1 - \bar{S}^{a1} \tag{14.2}$$

Pollutants in region 2 are given by

$$S^2 = S_e^2 - S^{21} - S_r^2 - \bar{S}^{a2} \tag{14.3}$$

It is assumed that the quantity of “exported” pollutants represents a given part of net emissions and is nonnegative[3]

$$S^{21} = \alpha^{21}(S_e^2 - S_r^2 - \bar{S}^{a2}) \tag{14.4}$$

[2] We here analyze a static allocation problem and neglect that pollutants accumulate over time. Compare chapter 15.

[3] We are only interested in inner solutions with S^i, $S^{21} \geqq 0$. Formally, nonnegativity constraints could be additionally introduced into the maximization problem of Appendix 14 A.

The resource is intersectorally and interregionally mobile, so that we have

$$\bar{R} = \sum_j \sum_i R_i^j + \sum_j \sum_i R_i^{rj} \tag{14.5}$$

Furthermore, the definitions

$$S_e^j = \sum_i S_i^{pj} \tag{14.6}$$

and

$$S_r^j = \sum_i S_i^{rj} \tag{14.7}$$

and Eqs. 3.1, 3.2, and 3.3 apply.

Regional Implications of a National Environmental Policy

In the following we assume that the definition of property rights for environmental use is vested with a national authority and that the national government maximizes social welfare for a system of regions ("politique pour la nation", Boudeville 1966). Environmental policy maximizes the welfare of the two-region system under restrictions 3.1 through 3.3 and 14.2 through 14.7. The applicable approach and its implications are illustrated in Appendix 14 A.

We can expect that optimal allocation dictates that interregional spillovers are accounted for in the shadow prices of the economy. The polluter-pays principle requires that a region bears the environmental costs that it causes in another area. Shadow prices should also reflect differences in environmental scarcity between regions. In the short run, we can expect that environmental scarcity prices will be differentiated regionally. In the long run, when all adjustments have taken place, there is, under certain conditions, a tendency towards the equalization of environmental shadow prices. Finally, we can also expect that the target values of environmental quality may differ among regions.

Regional Differentiation of the Emission Tax

Prices for Pollutants

From Eq. 14A.2j one obtains the shadow price of pollutants ambient in the environment:

$$\lambda_S^1 = \lambda_S^2 + \lambda^{21} \tag{14.8}$$

Because of Eqs. 14 A.2b and i we have

$$\lambda^{21} = \lambda_S^1 - \lambda_S^2 = -W_U^{1'}G^{1'} + W_U^{2'}G^{2'} \tag{14.9}$$

for the shadow price of the pollutants exported by region 2. The following three cases can be distinguished:

1. If there is no difference between the marginal damages $W_U^{j'}\, G^{j'}$ in both regions, then $\lambda^{21} = 0$ holds in the optimum, and the marginal evaluation of pollutants is identical for both regions.
2. If $\lambda^{21} > 0$, that is, if region 1 has a higher marginal damage than region 2, then one unit of pollutants is evaluated as being more important in region 1.
3. If $\lambda^{21} < 0$, one unit of pollutants causes a smaller marginal damage in region 1 than in region 2. The shadow price λ^{21} thus can be interpreted as representing "differential damage".

Price for Emissions

The different evaluation of pollutants appears in the shadow prices for emissions (emission tax rates). For the shadow price of emissions in region 1 we have

$$\lambda_{S_i^p}^1 = \lambda_S^1 = \lambda_{S_i^r}^1 = -W_U^{1'}G^{1'} = \frac{\lambda_R}{F_i^{r1'}} \tag{14.10}$$

In region 1 the shadow price of emissions corresponds to the shadow price of pollutants and the shadow price of abated emissions. Similarly, as in the model for a closed economy (compare Eqs. 4.6b and c), we have as a condition for the optimum that the emission tax rate must be equivalent to the prevented marginal damage and the marginal costs of abatement.

For the shadow price of emissions in region 2 we have

$$\lambda_{S_i^p}^2 = \lambda_S^2 + \alpha^{21}\lambda^{21} = \lambda_{S_i^r}^2 = -W_U^{2'}G^{2'} + \alpha^{21}\lambda^{21} = \frac{\lambda_R}{F_i^{r2'}} \tag{14.11}$$

The shadow price of emissions in region 2 is no longer identical with the evaluation of the pollutants in region 2. The following cases have to be delineated:

1. If no interregional diffusion of pollutants takes place, that is, $\alpha^{21} = 0$, the shadow price of emissions in region 2 is, in the optimum, equivalent to the marginal costs of abatement and the prevented marginal damage of region 2.

2. If a unit of pollution causes the same marginal damage in regions 1 and 2, that is, $\lambda^{21} = 0$, then it does not matter in terms of the evaluation of pollutants in which region a unit of pollution is released into the environment. A differential damage does not arise. The emission taxes in the two regions are identical.

3. If a unit of pollution causes a higher damage in region 1 than in region 2 ($\lambda^{21} > 0$), then the shadow price of emissions in the optimum is determined not only by the marginal damage caused in region 2 but also by the differential damage caused in region 1. The argument goes as follows: Region 2 is "relieved" by the diffusion of pollutants, and therefore its marginal damage decreases. On the other hand, the quantity of pollutants increases in region 1, and the marginal damage rises there. The polluters of region 2 have to bear the social costs of pollution which arise from region 2 as well as from region 1.

4. If a unit of pollution causes a smaller damage in region 1 than in region 2 ($\lambda^{21} < 0$), then the shadow price for emissions can be set lower compared to the situation described in item 3. In this case, region 1 is still sufficiently endowed with assimilative capacity. Since this assimilative capacity is not used by region 1, it can be utilized by region 2 through interregional diffusion.

Location Advantage

The regional differentiation of emission taxes affects the shadow prices of commodities and therefore the absolute price advantage or location advantage of a region. As implications we have

$$\lambda^1_{Q_i} = W^{1'}_{Q_i} + H^{1'}_i G^{1'} W^{1'}_U = W^{1'}_{Q_i} - H^{1'}_i \frac{\lambda_R}{F^{r1'}_i} \tag{14.12}$$

$$\lambda^2_{Q_i} = W^{2'}_{Q_i} + H^{2'}_i (G^{2'} W^{2'}_U - \alpha_{21}\lambda^{21}) = W^{2'}_{Q_i} - H^{2'}_i \frac{\lambda_R}{F^{r2'}_i} \tag{14.13}$$

The shadow price of a commodity is determined by its regional evaluation and by the environmental costs which arise in its production. The environmental costs have to be subtracted from the social evaluation; $\lambda^j_{Q_i}$ thus denotes the producers' price of commodity i, not the consumers' price. For region 2 the environmental costs contain not only the environmental damages of region 2 but also the differential damage which arises because of the interregional diffusion of pollutants.

Consider the case in which environmental policy is changed in such a way that interregional diffusion is explicitly considered. Then by assuming $\lambda^{21} > 0$, additional costs arise for region 2. The production incentive in region 2 for commodity i is reduced. In the case where $\lambda^{21} < 0$, on the other hand, region 2 can continue to transmit pollutants to region 1. Region 2 receives a production advantage because of the unused assimilative capacity in region 1.

The location advantage of region 2 also is influenced by the assimilative capacity of region 1. Assume that the assimilative capacity of region 1 is reduced. Then λ^{21} must rise, and the production incentive in region 2 will be smaller. On the other hand, if the assimilative capacity in region 1 is increased, λ^{21} will be smaller and the production incentive in region 2 will rise.

Diagrammatic Explanations

The implications of the regional allocation model may be explained diagrammatically. Figure 14-2 shows the marginal damage and the marginal abatement costs for region 1 (Fig. 14-2a) and region 2 (Fig. 14-2b). Because of Eq. 14.10 the emission tax rate in region 1 must equate prevented marginal damage with the marginal costs of pollution abatement. For region 2 the differential damage has to be taken into account because of Eq. 14.11.

In order to be able to interpret our results, we assume an initial situation in which both regions have the same characteristics and in which no interregional diffusion takes place. Then the optimal solution is identical for both regions. The shadow price for emissions is OT in both regions. This situation is depicted by Fig. 14-2.

The reader should note that Fig. 14-2 represents partial equilibrium analysis and does not contain all the interdependencies treated in the model. Thus, the marginal-cost curve of emission abatement presupposes an optimal value for λ_R. Furthermore, the marginal-damage curve will shift if the quantity of emissions OS^j varies with the output vector in both regions.

Beginning with a frame of reference providing identical conditions and an identical emission tax in both regions (Fig. 14-2), we analyze what causes a higher emission tax in region 2.

Greater Damage

A unit of pollution may cause a higher level of marginal damage (in value terms) for region 2 when $S^1 = S^2$. The marginal-damage curve in region 2 shifts upward. This may occur if region 2 has a higher population density because then a unit of pollution will cause greater damage. It is also con-

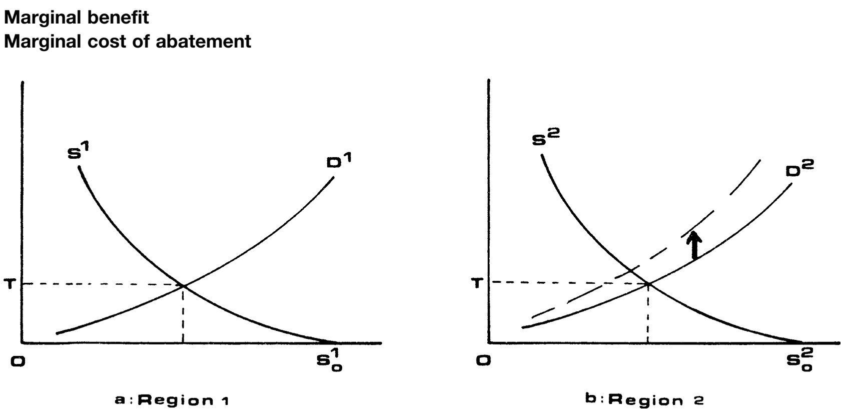

Fig. 14-2. Emission taxes with differences in evaluation

ceivable that the type of industrial activity in region 2 could account for the higher damage. Region 2 may have a different ecological system which is more vulnerable to pollution. The higher marginal damage implies a higher emission tax for region 2 in the optimum.

Higher Evaluation

The physical damage caused by one unit of pollution is valued higher in region 2 than in region 1. This may be due to differences in the respective preference functions; that is, residents of area 2 may be more environmentally minded. Also, citizens in region 2 may have a higher per capita income and may evaluate nature more highly. Finally, an area's value may be enhanced when it incorporates a specific function (recreation) or represents a value per se (amenity of the landscape). In these cases, the curve of the prevented marginal damage has to be drawn higher for region 2, and a higher emission tax has to be set (compare Fig. 14-2b).

Smaller Assimilative Capacity

Region 2 may have a smaller assimilative capacity than region 1. Let us assume that given an initial situation, the assimilative capacity of region 2 decreases. This means that the quantity of ambient pollutants increases (Fig. 14-3b). The emission tax in region 2 will have to be set higher, and the quantity of pollutants to be abated will increase. Note that in this case we have a complex chain of reactions which is not shown in Fig. 14-3b. The higher emission tax may lead to a smaller output, less pollution, and a shift in the cost curve of abatement. Also, the shadow price for the resource may change and thereby prompt the marginal-cost curve to shift again.

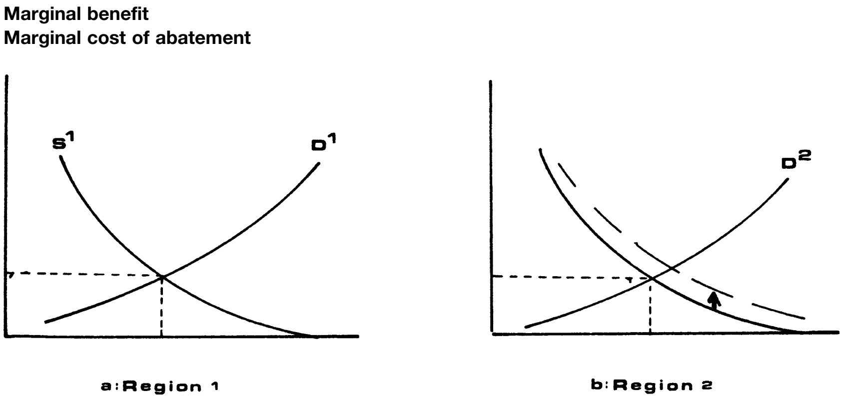

Fig. 14-3. Regional allocation with differences in assimilative capacity

Higher Demand for Assimilative Services

Region 2 may have a higher demand for assimilative services than region 1. The demand for assimilative services depends on such factors as the level of regional development, the industrial mix, and the population density. The higher demand for assimilative services of region 2 can also be attributed to the fact that region 2 uses a more pollution-intensive production technology and emits a greater quantity of pollutants for identical output vectors. This case should be treated analogously to the case where region 2 has a lower assimilative capacity.

Higher Costs of Abatement

Region 2 has higher marginal costs of abatement. This presupposes that the abatement technology varies regionally and that technical knowledge of abatement processes cannot be transferred interregionally, either because information concerning inventions in abatement technology meets with spatial obstacles or because innovations in both regions are not proportionately possible. This latter situation could arise if in one area older, less efficient abatement technologies exist. The disadvantageous marginal costs of abatement can also be based on a higher factor price in the case where partial immobility of factors exists. In Fig. 14-3 the case of disadvantageous marginal costs is illustrated by a higher curve of the marginal abatement costs. Note that the cost curve turns around the point of initial pollution with the cost curve having a higher slope (not drawn in Fig. 14-3).

The results can be treated comparably with the analysis of problems arising from international specialization. Those factors requiring regional differentiation of emission taxes also exhibit comparative advantages. The reader is reminded, however, that the institutional conditions for both problems are different. The basic difference is that internationally no effective environmental agency exists, whereas nationally an agency monitoring a two-region system is feasible.

Interregional Diffusion

The emission tax is influenced by interregional diffusion of pollutants. In Fig. 14-4 we analyze the effects of this diffusion. Let $\lambda^{21} > 0$. If interregional diffusion takes place and if region 2 exports pollutants, then, *ceteris paribus*, the marginal-cost curve of pollution abatement in region 2 shifts to the left because the quantity of ambient pollutants in the environment diminishes. In region 2 the tax rate and the quantity of abated pollution fall (arrow to the left in Fig. 14-4b). In region 1, on the other hand, the tax rate rises and the quantity of abated pollution increases (arrow in Fig. 14-4-a). If the interregional diffusion is not accounted for, region 2 will have a location advantage

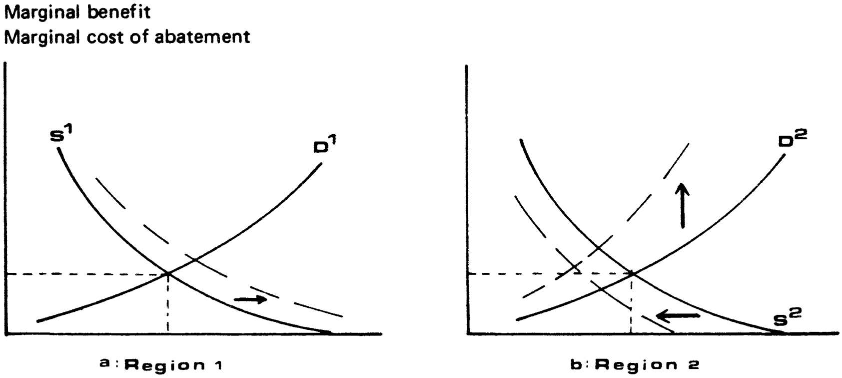

Fig. 14-4. Regional allocation and interregional diffusion

through this interregional-diffusion factor. This has the same effect as an extension of the assimilative capacity; region 1 bears social costs which it has not caused. If an environmental policy is initiated, the polluters of region 2 will have to bear the environmental costs which they have caused in region 1 (differential damage). If the differential damage is introduced by environmental policy, the marginal-damage curve in region 2 will shift upward (Fig. 14-4b). This implies that a higher emission tax will be set in region 2. Furthermore, the marginal-cost curve in region 2 will shift upward (Fig. 14-4b). This again implies that a higher emission tax will be set in region 2. Furthermore, the marginal-cost curve of abatement in region 2 will shift, since λ_R varies. Although we do not consider this effect further, it is important to recognize its potential impact.

Resource Mobility and Adjustment of Emission Taxes

If resources are totally mobile between the two regions and infinitely divisible, then the emission tax will adjust itself in the long run between the regions. This results from the following consideration:

Assume that in a given situation the assimilative capacity in region 2 is smaller than in region 1. Then, *ceteris paribus*, the emission tax in region 2 is initially higher. With a higher shadow price of emissions in region 2, the producers' price for commodities in this region is lower. Region 2 has a lower location advantage. With resources being mobile, firms leave region 2. Pollution in region 2 decreases, and it increases in region 1. The price of pollutants will fall in region 2 because of the lower level of pollution. In region 1, the price of pollutants will rise. Abatement will be stimulated in region 1, but marginal productivity of abatement will be reduced (that is, marginal abatement costs will rise in region 1). Thus, the emission tax in region 1 has to rise because of a higher level of pollution and because of increasing abatement costs. In region 2, however, the emission tax will be reduced. In the long run, the emission taxes in the two regions have to be identical if factors of production are completely mobile.

This model does not consider interregional trade because we did not distinguish between output and consumption goods. Interregional commodity exchange can also adjust the emission tax in the long run. Let us assume that we have identical production, pollution, and abatement functions for commodity *i* in both regions. Then the region which is richly endowed with assimilative capacity will specialize in the production of the pollution-intensive commodity. This implies that the demand for assimilative services increases in the region with environmental abundance. If we also assume a progressive increase of abatement costs, the emission tax will be adjusted accordingly between the regions. It can be shown that emission taxes will equalize under specific conditions, for instance identical and linear production and emission functions, identical and linear abatement functions, and identical and linearhomogeneous overall production technology (Siebert 1985, p. 140).

If the evaluation of environmental quality is determined by individual preferences, the mobility of residents also works toward an adjustment of the emission tax between the regions. Individuals will migrate to the region with a better environmental quality and increase the demand for environmental goods there. The emission tax has to rise. In the vacated region, however, the demand for environmental quality will decrease.[4]

One can expect that this long-run tendency toward an equalization of emission taxes will not be relevant given the limited planning horizon of practical policy. The structure of space is "congealed" at a given time in the sense of burned clay. This means that factors are partially immobile and that the environmental policy should not set the long-run optimal tax rates which are applicable for total mobility, but rather only those prices which consider the partial immobility of resources. The theoretically interesting phenomenon of emission-tax equalization does not relieve environmental policy of a regional differentiation of the emission tax.

Differences in Environmental Quality

Identical shadow prices for pollutants do not imply identical environmental qualities in both regions. Assuming $\lambda_S = \lambda_S^2$, we have from Eqs. 14.A.2b and 14.A.2i in the appendix:

$$\frac{W_U^{1'}[G^1(S^1)]}{W_U^{2'}[G^2(S^2)]} = \frac{G^{2'}(S^2)}{G^{1'}(S^1)} \tag{14.14}$$

[4] Compare the Tiebout theorem (1956).

Only if both the (concave) utility function and the (concave) damage function are identical in both regions, will $\lambda_S^1 = \lambda_S^2$ imply that environmental qualities are identical in both areas. If, however, the utility and damage functions differ, $\lambda_S^1 = \lambda_S^2$ does not necessarily imply identical environmental quality in the optimum.

Siting Issues and the National Interest

The location of private and public large-scale ventures (airports, power plants) has become a major political issue, especially in densely populated economies. No allocation problem arises when all layers of society experience a net benefit, i.e., the region (local community) and the nation both have a net advantage. A problem arises when the benefits of a large-scale project and its costs relate to different regions and when at least one layer of society (a region) experiences a net loss that cannot be compensated. Then, from a national perspective, a region has to experience a net loss if the system as a whole can gain. From the regional perspective some protection is warranted. We have a problem of a constitutional dimension. The basic question is whether the constitution of a country should protect a minority of citizens experiencing the opportunity costs (for instance, in a region) or whether a group of society can be expected to tolerate the opportunity costs in order to allow overall net benefits.

Regional Versus National Authorities

If environmental policy is to be regionalized, the question arises as to whether environmental policy should be undertaken by autonomous regional authorities or by the national government. This assignment problem may differ according to the prevailing organizational scheme, namely, whether the question applies to central states or to federal states. One basic problem concerns interregional spillovers. Either the administrated area must be large enough to internalize all externalities, so that there will be not interregional spillovers, or a mechanism must be found which will monitor interregional diffusion, implement an interregional-diffusion norm, or place an appropriate shadow price on the pollutants crossing regional borders. The assignment problem must be solved in such a way that a high-stack policy (that is, increasing the height of the stacks in order to get rid of pollution) is not undertaken by a region. If interregional spillover is a relevant problem, then handling the spillover is a precondition to the regionalization of environmental authorities.

Regional authorities have the advantage of being able to identify regional preferences through such mechanisms as referenda or party voting. Regionalization implies that to some extent people can determine their way of living without being controlled by decisions of the central government or even international agencies (such as the European Union). In the classical federal states such as Switzerland and the United States, regional preferences are assumed to differ among regions; goal conflicts are solved by regional authorities according to the preferences of the regional population. A pure federalism presupposes that no serious interregional spillovers exist. The role of the federal government is limited to a skeleton law on environmental protection to guarantee that spillovers are internalized.

Another, but related approach is Olson's concept of fiscal equivalence (1979). This approach describes an institutional arrangement in which the group of people benefiting from environmental policy (experiencing environmental damage) are more or less identical with those financing environmental improvement. The task of an institutional arrangement then consists in finding such a delineation of environmental regions that guarantees the spatial overlapping of benefits and costs. However, creating fiscal equivalence for different types of public goods (that is, schools, theaters, dumps, transportation systems, river systems, air regions) may create a net of multiple organizational units. Organizations for different types of public goods will be characterized by overlapping spatial areas and may present a system of differing spatial grids (Olson 1979). The organizational structure will be even more complex if the organizations not only provide public goods but also have taxing rights. Consequently, the question arises as to whether a set of different regions is a practical solution.

Applying the Tiebout theorem (1956) to environmental allocation, an optimal solution can be found for local environmental qualities under a set of given conditions. The most important prerequisite (Stiglitz 1977) is that interregional spillovers are not serious and that consumers are mobile and vote with their feet. Each voter will migrate to the region in which he can maximize his utility. An equilibrium is reached when no consumer is induced to change his location. The willingness to pay for the regional environmental qualities is expressed correctly. Thus, voting with one's feet will guarantee a Pareto-optimal environmental allocation.

Independent regional authorities will have a number of difficulties to overcome.

First, the consistent delineation of environmental regions creates severe problems. Since environmental media differ in spatial extent, regions related to different environmental media will overlap spatially. Also the interdependency existing among environmental regions because of technology and the economic system has to be considered because emissions released into one medium A can also be transmitted (at least partly) to medium B. Although these coordination problems will also arise for a national environmental policy, we can expect that independent regional authorities will have greater difficulties in trying to solve them.

Second, regional authorities are not likely to take into consideration the interdependency of regional welfare functions, that is, that the environmental quality of region 2 can also be an argument variable in the welfare function of region 1. Consequently, the institutionalization of independent regional authorities implies suboptimization.

Third, it is doubtful whether regional authorities will take into account the interregional diffusion of pollutants. The pollution-exporting region regards the export of pollutants as a welcome extension of its assimilative capacity. The price of environmental use is set too low in the pollution-exporting region; this region has a location advantage at the expense of other regions. In the importing regions, the shadow prices are set too high; they reduce the production of pollution and goods more than is economically desirable.

Some Restraints on Regional Authorities

The conflict between regional autonomy and the necessity to solve the spillover problem may require some restraints on regional authorities.

In the case of interregional bargaining among independent regional authorities, we can expect the same problems as occurred in the case of transfrontier pollution. The victim-pays solutions are very likely and experience suggests that even these solutions may not be easily implemented. Consequently, one may think about introducing some restraints, for instance, on grants by the national government, in order to induce solutions.[5] On an international scale, this approach is rather impractical.

Alternatively, national environmental policy could formulate "interregional-diffusion norms" for pollutants. These would define the quantity of pollutants that a region would be permitted to "export" via environmental systems to another area per period (for example, in the case of water management, the water quality of a tributary as it joins the main river). Thus, it would be conceivable to combine a system of independent water-management agencies (such as the *Agence de Bassins* in France) with a system of interregionaldiffusion norms. But diffusion norms cannot be fixed once and for all (in contrast to quality norms). Diffusion norms have to be adaptive to changes in population density, industry mix, environmental conditions, and scientific discoveries. It will be extremely difficult to change such diffusion norms in a world of independent regional agencies. A national agency could more easily adapt pollution shadow prices to new economic, ecological, and social developments.

Note that in the previous analysis we assumed that independent environmental agencies can determine the quality targets for regional systems. Alternatively, one can consider an institutional arrangement with a smaller regional autonomy. For instance, regional authorities could be empowered to impose a regional supplementary tax. Those regions with a strong environmental preference or with a special need for environmental protection could levy an additional tax besides those rates already established by the national agency.

Regional water associations (see chapter 8) represent an institutional setting which allows a regionalization of environmental policy. The delineation

[5] Introducing an additional restraint, for instance, by a reduction of grants from the federal government could transform the noncooperative game into a cooperative game.

of the environmental system (river system) can be easily achieved. Moreover, the spillover problem can be solved if water quality at the mouth of a river or of a tributary is specified by interregional bargaining or by national laws. Interregional diffusion norms then are identical to ambient standards at a given spot of a river and they can be considered as the target variable of environmental quality.

Regional Autonomy and Environmental Media

Solutions to the assignment problem vary according to the environmental media and according to the instruments used (compare taxonomy problem).

Noise is a regional problem, and so it may be partly controlled by regional authorities. However, since product norms should not be differentiated regionally, an antinoise policy must be nationalized.

Water-quality management can be handed over to regional authorities if interregional-diffusion norms can be controlled and if they can be easily altered to respond to changing needs. In the case of water, observe that interregional-diffusion norms are identical to ambient standards in a river, and these norms can be considered to be the target variables of environmental quality. If water management relies exclusively on emission taxes as set by regional authorities and does not incorporate interregional-diffusion norms, then the taxes should be determined so as to take into account downstream damages.

Bargaining may be necessary to set this tax. Such a procedure seems very impractical. Alternatively, one could conceive of a surcharge levied by some national or interregional agency that would encompass downstream damages. Again, this seems impractical. In the case of water management, the use of regional authorities operating within the constraints determined by interregional-diffusion norms seems to offer a practical solution. Only if the problem of interregional diffusion is negligible can a national emission tax be used.

In the case of air-quality management, the solution varies, again depending on the preferred policy instruments and the magnitude of interregional pollution. If such pollution is negligible, regional management can be utilized. Otherwise, air-quality management must be undertaken nationally, since bargaining among regions seems unrealistic. A national emission charge can be combined with a regional surcharge which is levied by regional authorities. Note that a regional surcharge can account for regional differences in tastes and environmental endowments. If interregional diffusion is of a significant magnitude, however, the surcharge must also account for damages in the polluted area. Consequently, the surcharge cannot be established by the polluting region. Once again, interregional diffusion complicates the picture and requires the imposition of a surcharge by a national or an interregional agency.

Toxic wastes and toxic materials contained in products should be controlled nationally according to liability rules or through product norms.

Environmental Equity and Specialization of Space

Welfare maximization for the nation as a whole can imply that regions will reach different welfare levels. Interregional specialization can also mean that regions will achieve differing amounts of environmental quality. This result can be in conflict with a spatially interpreted equity goal. Therefore, one possible strategy is to introduce restrictions on the interregional differences in welfare (Siebert 1975b). In practical economic policy, one can expect that the restrictions are not defined with respect to the regional welfare level, but rather in relation to the determining factors of regional welfare. Thus, articles 72 and 106 in the Constitution of the Federal Republic of Germany require that living conditions be similar for all regions. This requirement may be interpreted to mean a similarity in environmental quality. Therefore, we could introduce additional constraints into our allocation model, such as $U^1 = U^2$, which would require identical environmental quality among regions. Alternatively, we could require that a minimum quality $U^j \geq \bar{U}^j$ be reached in each region.

If the equity constraint is not formulated in terms of regional welfare, but rather is broken down into different constraints on welfare determinants, then the constraint becomes more restrictive through partitioning. Typical welfare determinants are social overhead capital, environmental quality, and income per capita. Identical welfare could be achieved in these regions by a judicious combination of these determinants. Interregional constraints on each welfare determinant, however, reduce the solution set considerably. In practice, constraints are not implemented rigorously and thus are used more as guidelines. Since these equity considerations may be thought of as a spatial implication of a welfare approach, a state of this type can be classified as a welfare state with a federal structure.

An alternative approach to equity restrictions on environmental quality is a specialization among regions, such as a "hot-spot policy" where pollution-intensive activities are concentrated in certain areas (for example, Sweden).[6] This spatial-separation approach attempts to bring about a specialization of national territory and relies heavily on land-use planning as an instrument of environmental-quality management. This approach allows for better protection of less polluted areas; at the same time, it concentrates the "public bad" in designated areas. Also, there is a strong incentive to locate the black spots near the border so that the burden is shifted to the neighbor (such as in the case of Sweden where black spots are located near Norway).

[6] Interregional spillovers may be of an intertemporal nature. Pollutants transported into a region may accumulate there over time. The problem then has to be analyzed as a cooperative or noncooperative differential game which shows the properties of a steady-state in a two-region system and the time paths of pollution in both regions towards the steady state.

Environmental Policy and Regional Planning

Environmental policy will have an impact on spatial structure. Regional planfling will influence environmental allocation in space. Will these policy areas work harmoniously and consistently?

Consistency relates to the following problems: (1) If there is only one policy target, do the policy instruments all work in the same direction? (2) Are the policy instruments consistent over time? (3) Do the policymakers at different levels all work toward attaining the target? (4) If there are different policy targets, to what extent is there a goal conflict, and are these goal conflicts resolved rationally?

Since environmental policy relates to different environmental media, environmental policy areas will overlap. A high emission tax for residuals in the atmosphere may introduce an incentive to emit these pollutants into the region's river system instead. We cannot fault individual firms or households for substituting processes at politically set prices. The problem is whether the policymaker can react adequately to changing conditions and whether the policymaker can anticipate the reactions of individuals. If the decision-making process of environmental policy is rather slow and emission taxes are rigid, inconsistencies in environmental policies can arise. It is necessary that policy instruments used for different media be coordinated: emission taxes should set the correct relative prices among pollutants for different media or, if one favors direct controls, the correct structure of emission norms.

Regional planning (or land-use planning) can be regarded as instrumental for environmental policy, especially by preventing pollution-intensive firms from locating in agglomerated areas. On the other hand, environmental policy may be an instrument of regional policy. Environmental policy can be considered an attempt to attribute social costs to economic activities. In this interpretation, environmental policy helps to correctly express regional comparative advantage. For instance, a region with a large endowment of assimilative capacity may experience an increase in its comparative advantage owing to environmental policy. A heavily industrialized area may have experienced an artificial comparative advantage before environmental policy was implemented. Its agglomeration economies may have been overestimated. If both regional planning and environmental policy are efficiency-oriented, one should not expect goal conflicts. However, if other targets such as environmental equity are introduced, then goal conflicts are likely to arise.

Finally, as is discussed in the following chapters, the time profile of an emission tax will influence the spatial structure at each moment in time, and the structure of space will influence the future allocation of space. If environmental policy has to correct its price signals very often, spatial structure will have a ratchet effect on future location decisions. Costs of adaptation are involved in adjusting spatial structure to the revised price signals.

Appendix 14 A: A Regional Allocation Model

Environmental policy maximizes the welfare of the two-region system. The Lagrangean expression is

$$
\begin{aligned}
L = {} & \sum W^j(Q_1^j, Q_2^j, U^j) - \sum_j \sum_i \lambda_{S_i^p}^j [H_i^j(Q_i^j) - S_i^{pj}] \\
& - \sum_j \sum_i \lambda_{Q_i}^j [Q_i^j - F_i^j(R_i^j)] - \sum_j \sum_i \lambda_{S_i^r}^j [S_i^{rj} - F_i^{rj}(R_i^{rj})] \\
& - \lambda_S^1 \Big(\sum_i S_i^{p1} - \sum_i S_i^{r1} + S^{21} - S^1 - \bar{S}^{a1} \Big) \\
& - \lambda_S^2 \Big(\sum_i S_i^{p2} - \sum_i S_i^{r2} - S^{21} - S^2 - \bar{S}^{a2} \Big) - \sum_j \lambda_U^i [U^j - G^j(S^j)] \\
& - \lambda_R \Big(\sum_j \sum_i R_i^j + \sum_j \sum_i R_i^{rj} - \bar{R} \Big) \\
& - \lambda^{21} \Big[\alpha^{21} \Big(\sum_i S_i^{p2} - \sum_i S_i^{r2} - \bar{S}^{a2} \Big) - S^{21} \Big]
\end{aligned}
\tag{14 A.1}
$$

The approach in 14 A.1 should be analyzed analogously to Eq. 4.5. The equations are the welfare function, pollution function, production function, pollution-abatement function, definition of ambient pollutants in the environment, damage function, and resource constraint.

The Kuhn-Tucker conditions are

$$\frac{\partial L}{\partial Q_i^j} = W_{Q_i}^{j\prime} - \lambda_{S_i^p}^j H_i^{j\prime} - \lambda_{Q_i}^j \leqslant 0 \qquad Q_i^j \frac{\partial L}{\partial Q_i^j} = 0 \tag{14 A.2a}$$

$$\frac{\partial L}{\partial U^j} = W_U^{j\prime} - \lambda_U^j \leqslant 0 \qquad U^j \frac{\partial L}{\partial U^j} = 0 \tag{14 A.2b}$$

$$\frac{\partial L}{\partial R_i^j} = \lambda_{Q_i}^j F_i^{j\prime} - \lambda_R \leqslant 0 \qquad R_i^j \frac{\partial L}{\partial R_i^j} = 0 \tag{14 A.2c}$$

$$\frac{\partial L}{\partial R_i^{rj}} = \lambda_{S_i^r}^j F_i^{rj\prime} - \lambda_R \leqslant 0 \qquad R_i^{rj} \frac{\partial L}{\partial R_i^{rj}} = 0 \tag{14 A.2d}$$

$$\frac{\partial L}{\partial S_i^{p1}} = \lambda_{S_i^p}^1 - \lambda_S^1 \leqslant 0 \qquad S_i^{p1} \frac{\partial L}{\partial S_i^{p1}} = 0 \tag{14 A.2e}$$

$$\frac{\partial L}{\partial S_i^{p2}} = \lambda_{S_i^p}^2 - \lambda_S^2 - \alpha^{21}\lambda^{21} \leqslant 0 \qquad S_i^{p2} \frac{\partial L}{\partial S_i^{p2}} = 0 \tag{14 A.2f}$$

$$\frac{\partial L}{\partial S_i^{r1}} = -\lambda^1_{S_i^r} + \lambda^1_S \leqslant 0 \qquad S_i^{r1}\frac{\partial L}{\partial S_i^{r1}} = 0 \tag{14 A.2g}$$

$$\frac{\partial L}{\partial S_i^{r2}} = -\lambda^2_{S_i^r} + \lambda^2_S + \alpha^{21}\lambda^{21} \leqslant 0 \qquad S_i^{r2}\frac{\partial L}{\partial S_i^{r2}} = 0 \tag{14 A.2h}$$

$$\frac{\partial L}{\partial S^j} = \lambda^j_S + \lambda^j_U G^j \leqslant 0 \qquad S^j\frac{\partial L}{\partial S^j} = 0 \tag{14 A.2i}$$

$$\frac{\partial L}{\partial S^{21}} = -\lambda^1_S + \lambda^2_S + \lambda^{21} \leqslant 0 \qquad S^{21}\frac{\partial L}{\partial S^{21}} = 0 \tag{14 A.2j}$$

$$\frac{\partial L}{\partial \lambda} \geqslant 0 \qquad \lambda\frac{\partial L}{\partial \lambda} = 0 \tag{14 A.2k}$$

These conditions should be compared to Appendix 4 B.

Part V
Environmental Allocation in Time and Under Uncertainty

15 Long-Term Aspects of Environmental Quality

In our analysis thus far, we have studied environmental allocation in a static context. However, environmental systems are used not only by one generation, but by a number of generations. Today's use of the environment may affect the role of the environment in the future. Consequently, the environmental-allocation problem also has to be interpreted over time.

Pollutants accumulate over time. Today's emissions influence environmental quality in the future. This problem of intergenerational allocation is studied in this chapter.

Environmental constraints have repercussions on economic growth by limiting the availability of the environment as a receptacle of waste; consequently, resources have to be used for environmental protection and cannot be allocated to production. This relationship of environmental policy and economic growth is studied in chapter 16.

Some of the impact of pollution will occur in the distant future, and we do not have adequate information on the specific effects. In contrast to our analysis so far, uncertainties are involved relating to the damage function, the accumulation of pollutants and possibly to environmental policy instruments. These problems are taken up in chapter 17.

The Problem

In this chapter, we are interested in the competing use of the environment as a good for public consumption and as a waste receptacle. If today's generation emits pollutants into the environment and if these pollutants accumulate over time, then environmental quality for future generations will be negatively affected. We want to examine, then, how the environment may be optimally allocated over time, what level of environmental quality should be envisioned for future periods, and what implications arise for the setting of a shadow price of environmental use over time. The interdependency between today's use of the environment and future environmental quality can be explained as follows:

1. A number of pollutants are accumulated by environmental systems and remain in the environment for several years, decades (as with DDT), or thousands of years (as in the case of radioactivity). Some pollutants that enter the environment today will harm future generations; that is, some pollutants will have long-term effects.

2. One cannot dismiss the possibility that pollutants will be responsible for irreversible damage to the ecological equilibrium in the future. There is the risk that changes may occur in the environmental system which humans may not be able to reverse.

3. Some environmental systems regenerate by delicate natural processes, such as take place in the production of oxygen by phytoplankton. Emissions can disturb these processes and influence the capability of environmental systems to regenerate over time. Similarly, the pollutants emitted into the environment today can impair the future assimilative capacity of environmental systems.

4. The capital stock in production and abatement and a given sectoral structure are passed on to the next generation; it may be unable to change these structures immediately because the mobility of labor and capital is insufficient.

5. We pass on a given production and abatement technology to future generations. Since the institutional setting of today's economy defines the incentives of finding new technologies, our institutional rules may also have an impact on the future.

Environmental use today influences future environmental quality through interdependencies in the ecological system as well as in the economic system. We therefore must decide to what extent the intertemporal interactions among generations should be considered in our current decisions.

The following questions arise: What environmental quality should be maintained today, and how much environmental quality should be left for future generations? Which emission technologies and how much capital in abatement processes should we hand over to future generations? How should the price of environmental use (or a system of emission standards) be set over time? How can one avoid that the price for emissions oscillates and that these oscillations cause wrong investments? For which planning period should an environmental agency maximize welfare? To what extent should minimal values (for example, for the quality of environmental media) be stated for irreversible damages in order to protect future generations? What kinds of shifts in demand for the public good "environment" come about over time (for example, shifts in preferences or shifts due to increases in income)? What is the magnitude of the income elasticity of demand for environmental quality? What are the effects of changes in demand on the price of environmental use? What adjustment processes take place for emissions when environmentalpolicy measures are introduced (for example, technological adjustment processes or location shifts)? How soon should the time path of prices be known so that the desired adjustment processes can operate without causing wrong investments?

In the following analysis, we restrict ourselves to developing a simple dynamic allocation model in which merely the accumulation of pollutants is taken into account as interdependency between periods.

Dynamic Model

We assume that the economic policymaker intends to maximize utility over time. The policymaker considers the utility of the existing generation, but he also takes into account the utility of future generations. The utility of future generations is discounted because of the time preference by a rate of $\delta > 0$. Welfare co for the planning period $[0,\infty]$ thus will be calculated at its discounted value:

$$\omega = \int_0^\infty e^{-\delta t} W(Q_1^t, Q_2^t, U^t)\, dt \tag{15.1}$$

Equation 15.1 raises two important issues. First, we assume that a social welfare function exists not only for one generation but for all future generations. All problems of information and institutional aspects discussed in chapter 5 are assumed away. Second, the normative problem arises as to whether we should discount the welfare of future generations and if so, by which discount rate.

The maximization of social welfare has to satisfy restrictions for every period. These constraints are known from the static allocation problem (chapter 4). Also, the quantity of pollution is given at the initial point of time 0, that is, $S(0) = \bar{S}$.

The maximization problem should at least incorporate an interdependency which connects the variables of different periods. In the following analysis we assume[1] that

$$\dot{S} = \sum S_i^p - \sum S_i^r - \overline{S^a} \tag{15.2}$$

This equation of motion represents the change in accumulated quantities of pollutants $\dot{S}$, emissions in one period $\sum S_i^p$, abated quantities of pollutants $\sum S_i^r$, and assimilated quantities of pollutants S^a. The implications of this approach are depicted in Appendix 15 B. Readers not familiar with control theory should first consult Appendix 15 A.

Implications

Implications that are related to a point in time, namely, the conditions for optimality that must be fulfilled in every single period, are equivalent to the implications of the static optimization approach.

[1] In Eq. 15.2 the case can obviously arise that, because of the exogenously given assimilative capacity $\overline{S^a}$, more pollutants are assimilated than the stock of pollutants plus net emissions. This case must be excluded. This can be done by assuming that a constant part of the stock of pollutants is reduced. For simplicity, we assume Eq. 15.2. It should be noted that Eq. 15.2 in this chapter replaces Eq. 3.4. New pollutants do not disappear automatically at the end of a period; rather, they expire at the rate $\overline{S^a}$.

1. From condition 15 B.4a it follows that the shadow price of commodities λ_{Qi} has to be set in such a way that it is equivalent to the social evaluation of a commodity for consumption minus its environmental costs. Observe that in condition 15 B.4a the shadow prices and marginal utilities of commodities are calculated at current value. However, condition 15 B.4a can also be interpreted in terms of discounted values.

2. From conditions 15 B.4c and d it follows that the resource price in production, as well as in abatement, is equal to the marginal value of the resource.

3. The dynamic allocation problem consists of finding use of the environment over time as a good for public consumption and as receptive medium such that the value of the welfare function will be maximized. This optimal allocation of environmental use over time and the resulting allocation of the resource in production and abatement (primal) correspond to an optimal time path of the shadow price (dual).

Condition 15 B.4g represents the equation of motion for the auxiliary variable $\mu(t)$ at current value:

$$-\dot{\mu} = -\delta\mu + W_U' G' \tag{15.3}$$

Equation 15.3 clearly shows that the change of the shadow price in period t at current value depends on the discount rate, the level of the shadow price, and the marginal damage in the period. From Eq. 15.3 it follows that

$$-\dot{\mu} \gtreqless 0 \qquad -\mu(t) \gtreqless -\frac{1}{\delta} W_U' G' \tag{15.3a}$$

$$-\dot{\mu} \gtreqless 0 \qquad -{}^{0}\mu(t) = -\mu(t) e^{-\delta t} \gtreqless -W_U' \frac{G'}{\delta} e^{-\delta t} \tag{15.3b}$$

The auxiliary variable $\mu(t)$, which in this approach is defined at current value, can be interpreted as follows: Let ${}^{0}\mu(t)$ denote the present value of $\mu(t)$. Then we have ${}^{0}\mu(t) = \mu(t)e^{-\mu t}$. The auxiliary variable ${}^{0}\mu(t)$ measures the marginal contribution of the state variable S at point t to the optimal value of the welfare function; that is, ${}^{0}\mu(t)$ tells us how one unit of pollution, ambient in the environment (entered exogenously into the economy at time t), changes the present value of the welfare function. Now ${}^{0}\mu\dot{S}$ defines the change in welfare caused by a variation in the state variable occurring at t, and $\mu(t) = {}^{0}\mu(t)e^{\delta t}$ denotes the change in value of the welfare function at current value (Arrow 1968, pp. 87, 93–94). And μ can be regarded as the shadow price for pollutants; it is negative.[2] The shadow price for pollutants

[2] The economic argument suggests that $dW/dS(t) = {}^{0}\mu(t) < 0$ and therefore $\mu(t) \leq 0$, for ${}^{0}\mu(t_0)$ states how a unit of pollution, put into the system at time t_0, affects the present value of the welfare function. From 15 B.4e it follows that $-\mu = \lambda_{S_i^p}$. Since $\lambda_{S_i^p} \geq 0$, $\mu \leq 0$ (that is, μ is not positive).

can also be viewed as a user cost. It represents the opportunity costs of today's environmental use to future generations since p indicates a change in the welfare function caused by an additional unit of pollution (that is, the welfare loss of future generations).

In Eq. 15.3b, ${}^{0}\mu$ characterizes the total marginal damage for all periods, that is, the damage in period t and in the future. Thus, when a unit of pollution is increased at t, the change of the welfare function is discounted to period 0. On the right hand side of Eq. 15.3b, we have the negative "capital" value of a pollutant ambient in the environment at period t (prevented marginal damage discounted to period 0). The *capital* value of a unit of pollution at the beginning of period t is the value of the utility flow (marginal damage) in this period divided by the discount rate.[3] This capital value is calculated only from the utility flow in period t and thus does not consider, as does $-\mu$, the damage in future periods. The right hand side of Eq. 15.3b can be regarded as the capitalized loss of period t, from a period-egoistic point of view.[4] The shadow price of pollutants $-\mu$, on the other hand, takes into account future periods. Thus, we obtained the following result.

If the total marginal loss for all periods is greater than the capitalized loss in period t, the shadow price of pollutants has to rise (case of a high future loss). If, on the other hand, the total marginal loss is smaller than the capitalized loss of period t, the shadow price of pollutants should fall (case of a low future loss).

4. The time profile of the shadow price of pollutants ambient in the environment influences the shadow prices of the other variables and therefore the adjustment processes of the system. With a high future damage and a rising shadow price of pollutants, the producers' price falls, the production of commodities (especially the pollution-intensive) is repressed, and the incentive for abatement rises (compare conditions 15b.3a through c). The temporal variation of the shadow price favoring high actual or high future prices is relevant for the steering of the economic system. A bias, for example, in favor of relatively high actual prices, causes a strong structural change between abatement and production. A policy fostering an increase in the shadow price penalizes the pollution-intensive sector and requires adjustment processes adequately strong in the initial periods.

Three Strategies for Dynamic Environmental Use

The canonical Eqs. 15.2 and 15.3 of the optimization problem allow a statement to be made about the optimal time path of the shadow price μ (t) for

---

[3] Note that the capital value can be determined by the interest rate and interest revenue. For an interest rate of 6 percent and an interest revenue of \$ 12 per period, the capital value amounts to \$ 200 at the beginning of the period.

[4] Note that the minus sign of the right-hand side of Eq. 15.3 ensures that we measure the marginal prevented damage.

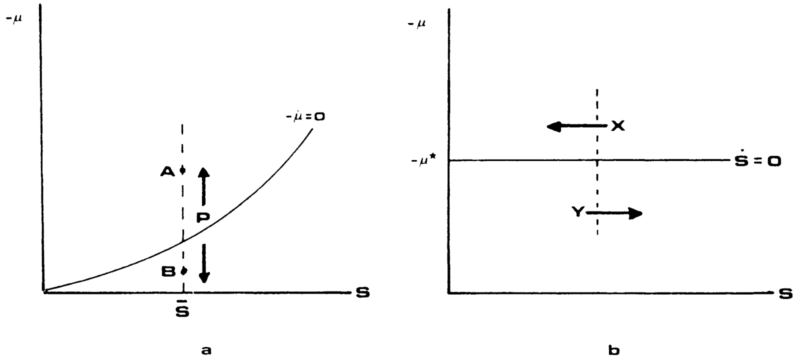

Fig. 15-1. The $-\dot{\mu} = 0$ curve and the $\dot{S} = 0$ curve

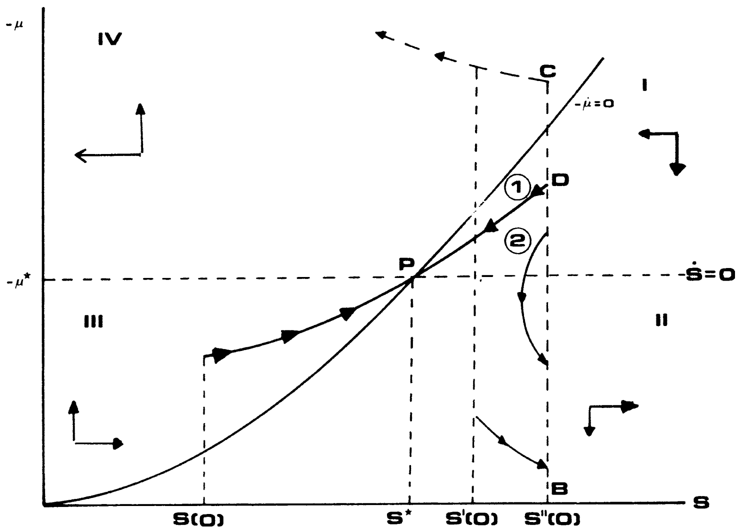

Fig. 15-2. Optimal stock of pollutants and time path of the emission tax

alternative initial situations S_0 (pollution level S in period 0). The optimal environmental allocation and the optimal time path of the shadow price $\mu(t)$ are depicted with the help of Figs. 15-1 and 15-2. First we discuss the equations $-\dot{\mu} = 0$ and $\dot{S} = 0$.

The $-\dot{\mu} = 0$ Curve

The equation of motion for the shadow price of pollutants, because of Eq. 15.3b, can be interpreted as follows: When the $-\dot{\mu} = 0$ curve applies,

$$-\dot{\mu} = 0 \Leftrightarrow -\delta\mu + W'_U G' = 0 \tag{15.4}$$

$$-\mu\,|_{\dot{\mu}=0} = -\frac{1}{\delta}\, W'_U G' \tag{15.4a}$$

The $-\mu$ = 0 curve progressively increases if $G''' < 0$ and $W''' > 0$ (Fig. 15-1a). This follows from

$$\frac{d(-\mu)}{dS} = -\frac{1}{\delta}(G'^2 W''_U + W'_U G'') > 0$$

$$\frac{d^2(-\mu)}{dS^2} = -\frac{1}{\delta}(2\, W''_U G' G'' + G'^3 W'''_U + W'_U G''' + W''_U G' G'') > 0$$

The $-\dot{\mu}$ = 0 curve characterizes situations in which the total marginal loss in all periods equals the (periodic-egoistic) capital value of a unit of pollution; that is, we see that for $\dot{\mu}$= 0, $-\mu$ = $(1/\delta)W'_U G'(S)$. The distance $\bar{S}P$ in Fig. 15-1a thus characterizes the periodic-egoistic capital value of an additional unit of pollution at point $\bar{S}$, as well as the total loss in all periods, that is, the shadow price of emissions.

For a given S, if the shadow price of emissions is set higher than the periodic-egoistic capital value of an additional unit of pollutant, that is, if $-\mu > \bar{S}P$ and $-(1/\delta)W'_U G'(\bar{S}) = \bar{S}P$ (point A), then the shadow price of the auxiliary variable has to rise in time because $-\mu > -(1/\delta)$-$W'_U G'(\bar{S})$ for $-\dot{\mu} > 0$. For all cases in which $-\mu$ lies above the $-\dot{\mu}$ = 0 curve, $-\mu$ has to rise (upward arrow in Fig. 15-1a). On the other hand, for a given S, if the shadow price of emissions is set lower than the periodic-egoistic capital value (point B), from $-\mu < -(1/\delta)W'_U G'(\bar{S})$ for $-\dot{\mu} < 0$ it follows that $-\mu$ falls. Cases of $-\mu < 0$ then lie beneath the $-\dot{\mu}$ = 0 curve (downward arrow in Fig. 15-1a).

The $\dot{S}$ = 0 Curve

The equation of motion 15.2 can be interpreted as follows: The resource use in production and in abatement activity depends on the level of the shadow price $-\dot{\mu}$. With an increasing $-\mu$, more resources are used in abatement and fewer are used in production. If the assimilative capacity is zero, we have

$$\dot{S} = \sum H_i\{F_i[R_i(-\mu)]\} - \sum F_i^r[R_i^r(-\mu)] \tag{15.5}$$

A high $-\mu$ reduces the production of pollutants and makes the quantity of abated pollutants increase. A low $-\mu$ implies a greater production of pollutants and a smaller abatement. One can expect a shadow price $-\mu^*$, for which $\dot{S}$ = 0, or

$$\dot{S} \gtrless 0 \Leftrightarrow \sum H_i\{F_i[R_i(-\mu)]\} \gtrless \sum F_i^r[R_i^r(-\mu)] \Leftrightarrow -\mu \lesseqgtr -\mu^* \tag{15.6}$$

Thus, the curve $\dot{S} = 0$ is a horizontal line with an axial section $-\mu^*$. Above the straight line $-\mu^*$, $\dot{S} < 0$ holds true, that is, S falls (point X). Beneath the straight line $-\mu^*$, $\dot{S} > 0$ is valid, that is, S increases (point Y in Fig. 15-1b).[5]

Phase Diagram

Combining Fig. 15-1a and b results in Fig. 15-2. The four regions in Fig. 15-2 indicate how the variables $-\mu$ and S change for alternative initial situations. The changes of $-\mu$ and S are represented by Pontryagin paths. The run of these Pontryagin paths is indicated by the arrows in the four regions.

In Fig. 15-2, P characterizes a situation in which the values $-\mu$ and S do not change. For a given initial level of pollution, the path to a steady state ($-\mu^*$, S^*) ensures the maximization of the welfare function. Both curves in Fig. 15-2 divide the first quadrant into four regions. Regions II and IV represent nonoptimal policies; regions I and III each contain a stable path.

Region IV depicts the path to an "ecological paradise." Assume that for an initial situation $S'(0)$ economic policymakers will adopt a tax which lies above the $\mu = 0$ curve. Then the production of commodities will be repressed and abatement stimulated until production contracts to zero.

Region II describes the path to an "environmental collapse." In the initial situation S' (0), if environmental policy chooses a shadow price which lies beneath the $-\mu = 0$ curve, then abatement is repressed and production increases. The quantity of pollutants rises, and environmental quality decreases.

Regions I and II both contain a stable path. For an initial situation $S''(0)$, if a shadow price is chosen that decreases in the long run, then the quantity of pollution is reduced to S^*. However, for an initial situation $S(0)$, the time profile of the shadow price must be chosen in such a way that the economy gradually adapts to the pollution norms (not yet exhausted in the initial situation). If an economy adopts a tax in region III (or I) and its associated time path, it is not ensured of attainment of the long-term optimal situation. A tax not lying on the stable path (for example, arrow 2) leads away from the optimal path. Figure 15-2 clearly depicts that the correct setting of the shadow price for intertemporal use represents a path over a sharp ridge. If the shadow price "loses its way" the system falls into the undesired (nonoptimal) regions II and IV. The strategy of region I and III, therefore, has to be interpreted as "moving slowly into a pollution norm".

[5] If the assimilative capacity is sufficiently large, the $\dot{S} = 0$ curve would coincide with the horizontal axis and a penalty on pollution would not be necessary.

Adjustment Costs

For practical economic policy, it cannot be excluded that the policymaker "jumps" between the regions of the phase diagram. Assume that the system has a quantity of emissions $S'(0)$ in the initial situation. If the economic policy adopts too low an emission tax, the system shifts to B. Now let the environmental issue be noticed by the voters, so that the politician is forced to react. If he now chooses a tax rate corresponding to point C (region IV), the system shifts in the wrong direction. The optimal tax on path 1 that should be applied in region II makes clear that this tax rate has to be set higher in situation S'' than in the initial situation S'. This demonstrates that the situation has deteriorated as a result of government intervention, compared to the initial situation S' (0). The higher tax rate indicates policy failure. The transition of the tax rate from point B to D also shows that wrong price signals had been set and that a revision of the tax rate brings about adjustment costs.

Social Discount Rate and Environmental Allocation

The social discount rate decisively influences the intertemporal use of resources. From Eq. 15.3 it follows that the higher the time preference (discount rate), the lower the absolute shadow price should be. The reduction of δ shifts the $-\mu = 0$ curve upward (compare Fig. 15-3a).

If a lower discount rate prevails, in contrast to path 1, environmental policy must adopt path 2 with a higher shadow price. If one considers the stable path 1 in region I of Fig. 15-2 for a given discount rate as a system of reference, then for a policy of a decreasing shadow price for emissions, a reduction of the discount rate implies an increase of the shadow price in every period (except for T = ∞).

The shadow-price increase is equivalent to a change in resource use over time. A lower discount rate produces a smaller quantity of emissions in the future (greater protection of future generations) and, at the same time, a price

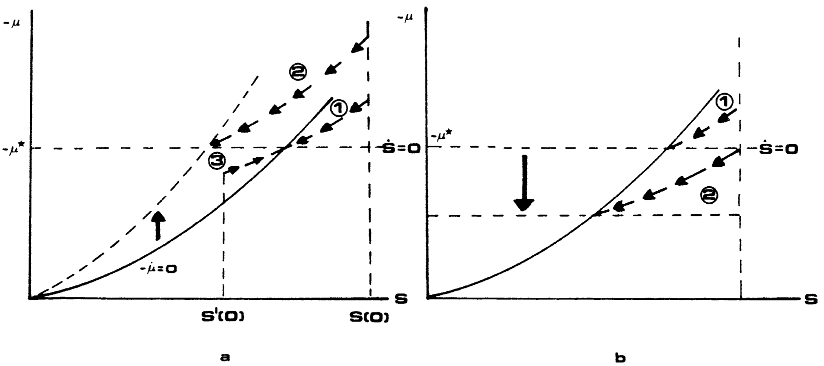

Fig. 15-3. Effects of an increase in the discount rate and in assimilative capacity

increase for use of the environment as a receptacle of pollution today. These higher costs of environmental use today can also be interpreted as opportunity costs, that is, forgone use of the resources employed in abatement. A lower discount rate raises the user costs and favors future generations.

For an initial situation $S'(0)$ and a policy of an increasing shadow price (path 3), a change in the discount rate can cause a reversal in policy. Now, instead of an increasing shadow price, a policy of a decreasing shadow price (path 2) has to be followed.

Further Determining Factors of the Shadow Price of Emissions

The simple allocation model presented takes into account only a single intertemporal context, namely, the accumulation of pollutants. There are, however, many other interdependencies among periods which also affect the shadow price of emissions and thus the intertemporal environmental use.

Assimilative Capacity

If the quantity of pollutants $\bar{S}^a$ assimilated by the environment increases parametrically, the $\dot{S} = 0$ curve shifts downward (Fig. 15-3b). The time path of the shadow price that should be chosen in pursuit of a greater assimilative capacity necessitates lower taxes now and in the future, but may not change the bias in the time profile of the shadow price.

Wealth of Future Generations

Future generations may be richer than we are today. Neglecting irreversibilities of allocation decisions, the wealth of future generations may favor the adoption of a high discount rate and a low shadow price for pollutants.

Technical Progress

Wealth of future generations can also manifest itself through improved technical knowledge. If one expects that resources will be used with greater productivity in the future, or that the production of commodities and emission technologies will be less pollution-intensive, we can set a lower shadow price today, compared to path 1 in Fig. 15-2.

Also, technical progress in abatement activities permits today's shadow price to be set lower. Technical progress, then, ensures that in spite of a high pollution level in the initial period, a lower pollution level can be attained in the future. Technical progress that reduces pollution in production and encourages improvements in the abatement technology allows one to set a lower tax rate at present (compared to path 1 in Fig. 15-2).

If it is presumed that technical progress in abatement depends on the emission-tax level, then the statement must be corrected to account for the long time lag of the technological incentive effect of an emission tax. The endogenization of technical progress in abatement and emission technology (dependent on the level of the emission tax) possibly causes a change in the time profile of the shadow price in favor of higher actual prices.

The abatement technology is specific to environmental media and economic sectors. Therefore, it is possible that technical progress in abatement may differ among the sectors and environmental media. If technical progress in future abatement favors the pollution-intensive sector, the shadow price for emissions can be set lower.

Capital Formation in Abatement

If a policy of a decreasing shadow price for emissions over time is pursued and if economic agents expect $-\mu$ to be constant, then too much capital will be tied up in abatement. This implies a misallocation of resources. This distorted allocation can be changed in the long run only if the excessive capital locked in abatement is mobilized via depreciation. The longer it takes to depreciate, the stronger the misdirection of capital will be.

An analogous argument applies to labor used in the abatement branch, provided that labor is temporally immobile and labor mobility is connected with costs (retraining, migration costs, costs of frictional unemployment). Furthermore, we can apply an analogous argument to the factors used in the improvement of assimilative capacity. Capital formation and partial immobility of labor in the abatement branch require a lower shadow price in the initial periods (compared to path 1 in Fig. 15-2).

Here, the importance of announcement effects becomes distinct. It seems to be more effective to influence private investments with an appropriate fixing of the shadow price than to moderate the effects of a wrong fixing of prices through policy instruments.

Sectoral Structure and Immobility of Factors

If one considers a two-sector model with a pollution-intensive and an environmentally favorable sector, a policy of a decreasing emission tax means that the pollution-intensive sector is repressed in the initial situation. Capital and labor migrate to the environmentally favorable sector (and costs of friction occur). In the course of time, however, the emission tax is decreased, so that the status of the time-consuming reallocation process is changed while the reallocation itself continues. With a falling tax rate, reallocation has to be partly canceled.

The temporal immobility of invested capital and labor and the adjustment processes that come about from a change in the sectoral structure require that the shadow price of emissions be set lower than in earlier periods.

Longevity of Pollutants

The pool of pollutants in any period consists of short- and long-lived pollutants. If, *ceteris paribus*, the composition of pollutants changes while long-lived pollutants increase relative to short-lived pollutants, then the actual shadow price will have to be set higher.

Other Factors

Intertemporal environmental allocation is influenced by other determinants, such as the risk of unknown future damages, the risk of irreversibilities (see chapter 17), and location decisions.

The previous considerations, which are not contained in the simple model, represent a number of significant factors relevant to setting shadow prices for emissions. These factors indicate that regions and stable paths which differ from those shown in Fig. 15-2 can be obtained.

Appendix 15 A: Control Theory[6]

If x denotes the state variable of a system and m the control variable, the control problem is

$$\max_{\{m(t)\}} J = \int_{t_0}^{\infty} e^{-\delta t} I(x, m, t)\, dt \qquad (15\ \text{A.1})$$

subject to the restrictions

$$\dot{x} = f(x, m, t) \qquad x(t_0) = x_0 \qquad \{m(t)\} \in U$$

where I (...) and f (...) are continuously differentiable functions; t_0 and x_0 are parameters (namely, t_0 characterizes the initial point in time and x_0 the initial value of the state variable); $\{m\ (t)\}$ is the control trajectory, which has to be an element of the control set U. The integral of the values of the I function from time t_0 to infinity must be maximized. The $\dot{x}$ function is the equation of motion of the system.

The maximum principle is applied while the Hamiltonian function is defined as $\tilde{H}(x, m, t) = I\ (x, m, t) + I\ (x, m, t)$, and its value is maximized at every point in time by a convenient choice of time paths $\{m\ (t)\}$, $\{\mu(t)\}$, and $\{x\ (t)\}$.

[6] See A.C. Chiang, Elements of Dynamic Optimization (New York 2000).

The maximization of the value for the $\tilde{H}$ function at every point in time in the planning period t e [0, ∞] requires the fulfillment of the following necessary conditions:

$$\frac{\partial \tilde{H}}{\partial m} = 0 \tag{15 A.2a}$$

$$\dot{x} = \frac{\partial \tilde{H}}{\partial \mu} \tag{15 A.2b}$$

$$\dot{\mu} = \mu \delta - \frac{\partial \tilde{H}}{\partial x} \tag{15 A.2c}$$

The maximization of the Hamiltonian function for every period (that is, a convenient choice of the control variables at every point of the optimal trajectory) is ensured by $\partial\tilde{H}/\partial m = 0$ (if no further restrictions occur). The equation $\dot{x} = \partial\tilde{H}/\partial\mu$ represents the equation of motion of the system. Note that equation 15 A.2b is obtained by differentiating the Hamiltonian function with respect to the multiplier and that it yields the constraint of the system, similar to static optimization problems.

The Hamiltonian function can be formulated at present (discounted) value or at current value. Shadow prices must be interpreted in the same way. The last paragraph used the formulation at current value. The value of the $\tilde{H}$ function, as well as the shadow price, should be interpreted at current value in this case.

In order to determine the transversality conditions, define a K-function according to Long and Vousden (1977) with

$$K(T, \xi) = \xi x(T) \tag{15 A.3}$$

where T is terminal time and ζ is a multiplier relating to the state variable in terminal time. Then we have as terminal conditions

$$\xi x(T) = 0 \quad \xi \geqslant 0 \tag{15 A.3a}$$

$$\frac{\partial K}{\partial x(T)} = \xi = e^{-\delta T} \mu(T) \tag{15 A.3b}$$

$$\frac{\partial J}{\partial T} = e^{-\delta T} H(T) = 0 \tag{15 A.3c}$$

15 A.3 c determines terminal time T. If the Hamiltonian, that is the performance indicator of a period T, does not contribute any more to present value

of the target function, it is not worthwhile to continue the program. Note that this condition can only be interpreted for finite solutions because

$$\lim e^{-\delta T}_{T\to\infty} \to 0.$$

Equations 15 A.3 a and b imply

$e^{-\delta T}\mu(T)x(T) = 0$ for finite time.

If additional restrictions $g(x)$ occur, the Lagrangean function is

$$\tilde{L} = \tilde{H} + \tilde{\lambda}_j g(x)$$

$$\tilde{H} = I(x,m,t) + \mu f(x,m,t) \tag{15 A.4}$$

where the Lagrangean function and multipliers are noted at current value. Then the necessary conditions are

$$\frac{\partial \tilde{L}}{\partial m} \leqslant 0 \quad m\frac{\partial \tilde{L}}{\partial m} = 0 \tag{15 A.4-a}$$

$$\dot{\mu} = \mu\delta - \frac{\partial \tilde{L}}{\partial x} \tag{15 A.4-b}$$

$$\dot{x} = \frac{\partial \tilde{L}}{\partial x} \tag{15 A.4-c}$$

The transversahity conditions 15 A.3a–b hold; condition 15 A.3c changes into

$$e^{-\delta T} L(T) = 0 \tag{15 A.4-d}$$

Table 15 A-1. Optimality conditions

Present values	Current values
$H = I(x,m,t)e^{-\delta t} + \lambda f(x,m,t) + \lambda_j(\ldots)$	$\tilde{H} = I(x,m,t) + \mu f(x,m,t)$
$\frac{\partial H}{\partial m} = 0$	$\frac{\partial \tilde{H}}{\partial m} = 0$
$\lambda = -\frac{\partial H}{\partial x}$	$\dot{\mu} = \delta\mu - \frac{\partial \tilde{H}}{\partial x}$

Here $\tilde{H} = He^{\delta t}$, $\mu = \lambda e^{\delta t}$, $\tilde{\lambda}_j = \lambda_j e^{\delta t}$, and $\dot{\lambda} e^{\delta t} = \dot{\mu} - \delta\mu$.

Table 15 A-1 compares the formulation at present value and at current value. For $\lambda = \partial\tilde{H}/\partial x$ it follows by definition that $\mu = \delta\alpha - \partial\tilde{H}/\partial x$. If $\partial H/\partial m = 0$, we have also $\partial\tilde{H}/\partial m = 0$ because $\partial H/\partial m = (\partial\tilde{H}/\partial m)e^{-\delta t}$.

Appendix 15 B: A Dynamic Allocation Model

The allocation problem for environmental use is presented in its dynamic aspect by the maximization of a welfare function as

$$\omega = \int_0^\infty e^{-\delta t} W(Q_1, Q_2, U)\, dt \qquad (15\ \text{B.1})$$

under the following restrictions:

$$\dot{S} = \sum S_i^p - \sum S_i^r - \overline{S^a} \qquad (15\ \text{B.2})$$

where $\overline{S^a}$ denotes the quantity of pollutants that is assimilated per period. Equation 15 B.2 is the equation of motion for the system which indicates to what extent the pool of pollutants varies per period.

The initial condition of the system is given by

$$S(0) = \bar{S} \qquad (15\ \text{B.3})$$

Furthermore, the restrictions of the static allocation approach of Eqs. 3.1 through 3.6 apply for every period. If the problem is formulated in periodical values, the maximization problem is

$$\begin{aligned} L = {} & W(Q_1, Q_2, U) + \mu\left(\sum S_i^p - \sum S_i^r - \bar{S}^a\right) - \sum_i \\ & - \sum_i \lambda_{Q_i}[Q_i - F_i(R_i)] \\ & - \sum_i \lambda_{S_i^r}[S_i^r - F_i^r(R_i^r)] \\ & - \lambda_U[U - G(S)] \\ & - \lambda_R\left(\sum R_i + \sum R_i^r - \bar{R}\right) \text{max} \end{aligned}$$

Necessary conditions for an optimum are

$$\frac{\partial L}{\partial Q_i} = W'_{Q_i} - \lambda_{S^p_i} H'_i - \lambda_{Q_i} \leqslant 0 \qquad Q_i \geqslant 0 \qquad Q_i \frac{\partial L}{\partial Q_i} = 0 \tag{15 B.4a}$$

$$\frac{\partial L}{\partial U} = W'_U - \lambda_U \leqslant 0 \qquad U \geqslant 0 \qquad U \frac{\partial L}{\partial U} = 0 \tag{15 B.4b}$$

$$\frac{\partial L}{\partial R_i} = \lambda_{Q_i} F'_i - \lambda_R \leqslant 0 \qquad R_i \geqslant 0 \qquad R_i \frac{\partial L}{\partial R} = 0 \tag{15 B.4c}$$

$$\frac{\partial L}{\partial R^r_i} = \lambda_{S^r_i} F^{r'}_i - \lambda_R \leqslant 0 \qquad R^r_i \geqslant 0 \qquad R^r_i \frac{\partial L}{\partial R^r_i} = 0 \tag{15 B.4d}$$

$$\frac{\partial L}{\partial S^p_i} = \lambda_{S^p_i} + \mu \leqslant 0 \qquad S^p_i \geqslant 0 \qquad S^p_i \frac{\partial L}{\partial S^p_i} = 0 \tag{15 B.4e}$$

$$\frac{\partial L}{\partial S^r_i} = -\lambda_{S^r_i} - \mu \leqslant 0 \qquad S^r_i \geqslant 0 \qquad S^r_i \frac{\partial L}{\partial S^r_i} = 0 \tag{15 B.4f}$$

$$\dot{\mu} = \delta\mu - \lambda_U G' \tag{15 B.4g}$$

(The derivations in relation to the multipliers are not reproduced here.) It should be noted that the above program is formulated at current values. For purposes of simplification, the tilde for L and λ_j is left out.

Implications 15n B.4a to f of the dynamic approach are equivalent to implications 4 B.1 through 4-B.9 of the static approach (compare Appendix 4 B). The conditions (15 B.4g) in both problems are identical. As an additional condition of the dynamic optimization approach, the equation of motion 15 B.2 applies.

It has been assumed for the arguments presented in chapter 11 that environmental quality does not decrease to zero; thus $U > 0$. It has also been assumed that both sectors produce, so that R_i, Q_i, $S^p_i > 0$. Then, presuming that an environmental policy will be pursued, and therefore the conditions $\lambda_{S^r_i} > 0$ and $R^r_i > 0$ are fulfilled, the optimal conditions of the static optimization approach follow from the restrictions of 15 B.4 for every period.

16 EconomicGrowth, Sustainability, and Environmental Quality

Ecologists believe that one of the important reasons for the existence of the environmental problem stems from the emphasis on growth by the industrialized states as well as the developing countries. They point out that growth has been possible only at the expense of the environment. They postulate that growth rates were so high because the waste and pollutants from production and increased consumpution had been unscrupulously released into the environment without consideration of their effects. The destruction of the environment, the impairment in the quality of elemental environmental services, the deterioration of air quality, and the contamination of seas, rivers, and lakes were not taken into account in economic calculations. In sum, the social costs of growth were not included in economic analyses. We have, so to speak, grown to the detriment of the environment. These arguments lead to the following questions: By which indicators should growth be measured? Does a halt in growth present a convenient measure for the improvement of environmental quality? What are the effects of economic growth on environmental quality? To what extent is economic growth restricted by a limited supply of natural resources? Is economic growth sustainable? What are the economic policy implications of sustainability?

Interdependencies Between Environmental Quality, Growth, and Resources

There is a relationship between economic growth, environmental quality, and natural resources. Economic growth as an increase in economic activity generates pollutants, and this means a reduction of environmental quality. Natural resources represent an important input of economic activity; they feed the growth process. These relationships are illustrated in Fig. 16-1 in a very simplified way. We assume that for a given technology the production function is characterized by decreasing marginal productivity (quadrant IV). With an increasing output, emissions will also rise (quadrant I). Resources can also be used in abatement (quadrant III).

If the total resource stock $O\bar{R}$ (available in one period) is used in production, a maximal national product is attained (point B). If, on the other hand, only the resource quantity OC is used in production (and $\bar{R}C$ in abatement), emissions can be totally prevented by abatement (point A, compare also Fig. 3-3.).

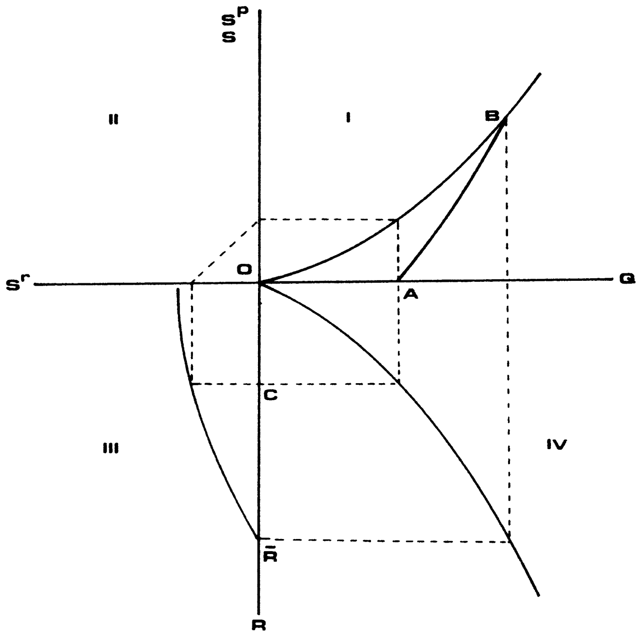

Fig. 16-1. Goal conflict between environmental quality and output

Curve AB expresses that, under the simplified assumptions, emissions rise with output. There is a goal conflict between environmental quality and output or growth.

Technical progress in production shifts the production function to the right (quadrant IV), the abatement function to the left (quadrant III), and the emission function downward (quadrant I). In these cases, curve AB shifts to the right. In addition, the increase in the resource stock shifts curve AB to the right. The goal conflict between growth and environmental quality is then moderated.

Assume that the resources available for production are reduced. In this case, curve AB shifts to the left, and the goal conflict between environmental quality and output is intensified. If we then want to maintain a given output level, environmental quality will have to decline.

Growth and Environmental Degradation

In order to analyze the interdependence between economic growth and environmental quality, refer to the models in chapters 3 and 15. For purposes of simplification, we reduce the two-sector model to one sector; that is, the economy consists of one sector only. Let the resource R now be the capital

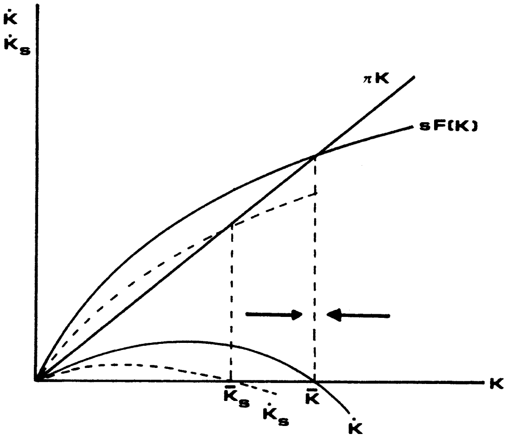

Fig. 16-2. Capital accumulation

stock K, so that the production function becomes $Q = F(K)$. The emission function, according to Eq. 3.1, is written as $S^p = Z(K)$; that is, emissions depend on input. From Eq. 3.1 a we know that a concave production function implies a convex emission function Z; with $Z' > 0$, $Z'' > 0$. If it is assumed that pollutants are assimilated at a given rate α and if one disregards abatement, the equation of motion for pollutants[1] is

$$\dot{S} = Z(K) - \alpha S \qquad (16.1)$$

Contrary to the models in chapters 3 and 16, capital formation is explicitly taken into consideration. Net capital accumulation is given as savings minus depreciation; s denotes the propensity to save, and π is the depreciation rate of the capital stock:

$$\dot{K} = sF(K) - \pi K \qquad (16.2)$$

Equation 16.2 is explained in Fig. 16-2 which shows the components $sF(K)$ and πK of the $\dot{K}$ curve in the $\dot{K}+K$ space. The $\dot{K}$ curve is affected by the following: If K < $\bar{K}$, then $\dot{K} > 0$, that is, the capital stock increases. If $K > \bar{K}$, then $\dot{K} < 0$, that is, the capital stock decreases.

In the following analysis, we discuss how the system described by Eqs. 16.1 and 16.2 behaves over time.

Zero Price of Environmental Use

In an explication model we ask toward which long-term equilibrium the economy will move if the environment can be used at a zero price. A long-run

[1] Compare Eq. 15.2.

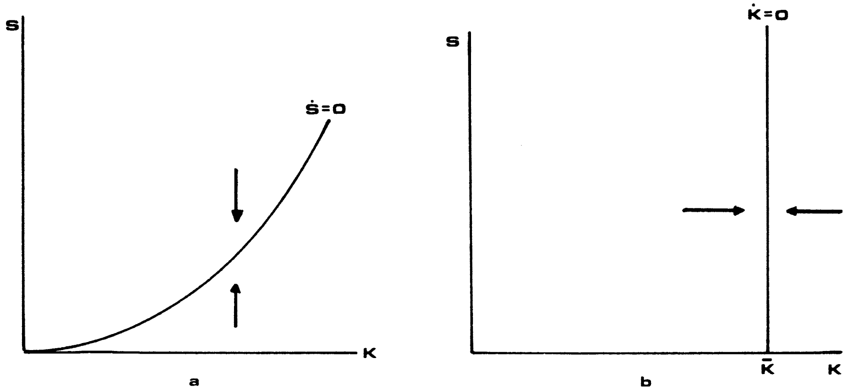

Fig. 16-3. The $\dot{S} = 0$ curve and the $\dot{K} = 0$ curve

equilibrium, or steady state, is given when a capital stock and a stock of pollutants are reached which will not change; that is, we have $\dot{S} = 0$ and $\dot{K} = 0$. Consequently, we must search for conditions under which such a long-run equilibrium will come about.

When the $\dot{S} = 0$ curve holds,

$$\dot{S} = 0 \Leftrightarrow Z(K) = \alpha S$$

$$\left.\frac{dS}{dK}\right|_{\dot{S}=0} = \frac{Z'}{\alpha} > 0$$

The $\dot{S} = 0$ curve increases progressively since $d^2S/dK^2 = Z''/\alpha > 0$. Consider a given K. A point on the $\dot{S} = 0$ curve characterizes the quantity of emissions $Z(K)$ for which $Z(K) = \alpha S$. The situation $Z(K) > \alpha S$ thus lies below the $\dot{S} = 0$ curve. There S has to rise. For $Z(K) < \alpha S$ (above the $\dot{S} = 0$ curve), we have $\dot{S} < 0$, that is, S falls (Fig. 16-3 a). The $\dot{S} = 0$ curve shifts with a parametric change in α and the Z function. If the abatement rate of pollutants falls, the $\dot{S} = 0$ curve shifts upward. The same may be said if the emission technology deteriorates.

For the $\dot{K} = 0$ curve, we have $sF(K) = \pi K$, so that a capital stock $\bar{K}$ exists which generates exactly those savings that offset the depreciation of the capital stock. If $K < \bar{K}$, then $sF(K) > \pi K$ will hold true since with decreasing values of K, the output and thus savings decrease underproportionally. For $K < \bar{K}$, we have $\dot{K} > 0$. If $K > \bar{K}$, $sF(K) < \pi K$ holds, because with greater values of K, the output increases underproportionally. Consequently, $\dot{K} < 0$ when K > $\bar{K}$ (Fig. 16-3b). The locus of $\bar{K}$ varies parametrically with π and s. If the depreciation rate of capital becomes smaller, $\bar{K}$ shifts to the right. This is also applicable if the tendency to save rises.

Combining Figs. 16-2 and 16-3, we obtain a phase diagram of the economy in which no environmental policy is undertaken (Fig. 16-4a). Arrows indicate

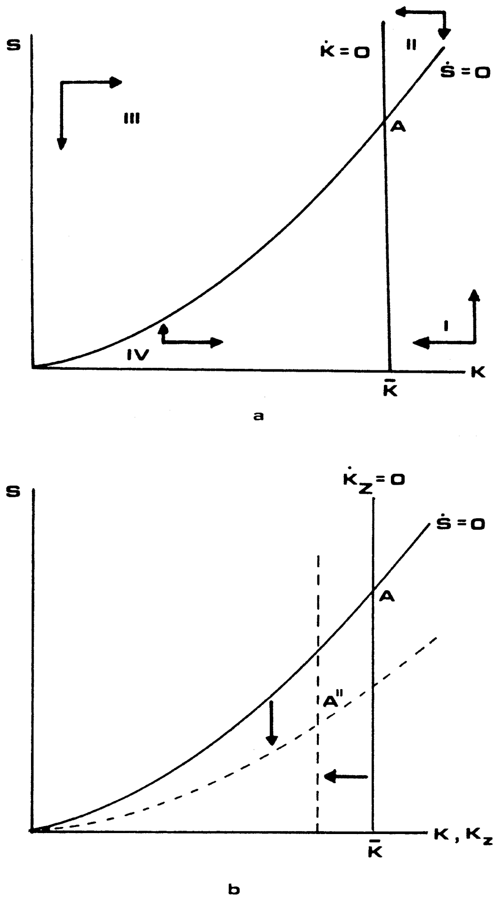

Fig. 16-4. Steady state with accumulation of pollutants and environmental constraints

the directions of movement from a given location. The phase diagram is partitioned into four regions.

In the long run, a situation A with a capital stock $\bar{K}$ will be reached. The capital stock thus does not grow any more in this situation. This result is known from classical and neoclassical growth models. For a given technical knowledge and supply of labor, capital formation comes to a standstill in the long run, the growth rate of output becomes zero, and the economy reaches a stationary state. Growth is limited by the declining marginal productivity of capital. The rate of return falls, and capital accumulation becomes smaller and smaller.

In the long run, the accumulation of pollutants will also stop. The amount of pollutants absorbed by the environment (aS) will equal those pollutants simultaneously introduced into the environment by production (point A lies on the $\dot{S} = 0$ curve). Pollution comes about as a consequence of the growth process. If one were to assume an unfavorable emission technology $\tilde{Z}$ with $\tilde{Z}(K) > Z(K)$, a higher pollution stock for $\bar{K}$ would arise. At the same time, it becomes clear that in this context growth is interpreted "quantitatively" and not with consideration to environmental quality.

Consider region IV in Fig. 16-4a with an initial situation characterized by a small capital stock and a small stock of pollutants. Capital will grow. With capital accumulation, the stock of pollutants will increase. On a stable path in region IV we reach A. Assume, however, that we are in region III with a small capital stock and a large stock of pollutants. Then capital will increase and add to the stock of pollutants; but more pollutants will be depreciated, so in the long run, situation A can also be attained.

If an economy is endowed with a high capital stock initially (with $K > \bar{K}$),it will not be able to maintain this situation since this stock will wear out at a rate stronger than that in which capital formation can take place. In region I the emissions rise; in region II they fall.

Negative Productivity Effect of Pollutants

Pollutants ambient in the environment may have a negative effect on output, as indicated by Eq. 3.8, so that

$$Q = F(K, S) \quad \text{with} \quad F_S < 0,\ F_{SS} < 0,\ F_{KS} = 0 \tag{16.3}$$

While the $\dot{S} = 0$ curve is not influenced by this assumption, the negative productivity of pollutants affects output and the accumulation of capital. The equation of motion of the capital stock now becomes

$$\dot{K}_S = sF(K, S) - \pi K \tag{16.4}$$

Note that Eq. 16.4 substitutes for Eq. 16-2. From Fig. 16-2 we see that the $\dot{K}_S = 0$ curve lies below the $\dot{K} = 0$ curve. We have

$$\left.\frac{dS}{dK}\right|_{\dot{K}=0} = \frac{sF_K - \pi}{-sF_S} \tag{16.4a}$$

$$\frac{dS}{dK} \gtrless 0 \Leftrightarrow K \lesseqgtr \tilde{K} \quad \text{with} \quad \tilde{K} \Leftrightarrow sF_K = \pi \tag{16.4b}$$

With an increasing capital stock, S rises at first, reaches a maximum for $\tilde{K}$, and then falls. The negative impact of the productivity effect implies that less can be produced in comparison with the situation where $F_S = 0$ and that capital formation will also become smaller.

The $\dot{K}_S = 0$ curve is shown in Fig. 16-5 a. Above the $\dot{K}_S = 0$ curve we have $sF(K, S) < \pi K$ since a high S has a negative effect on output and therefore on

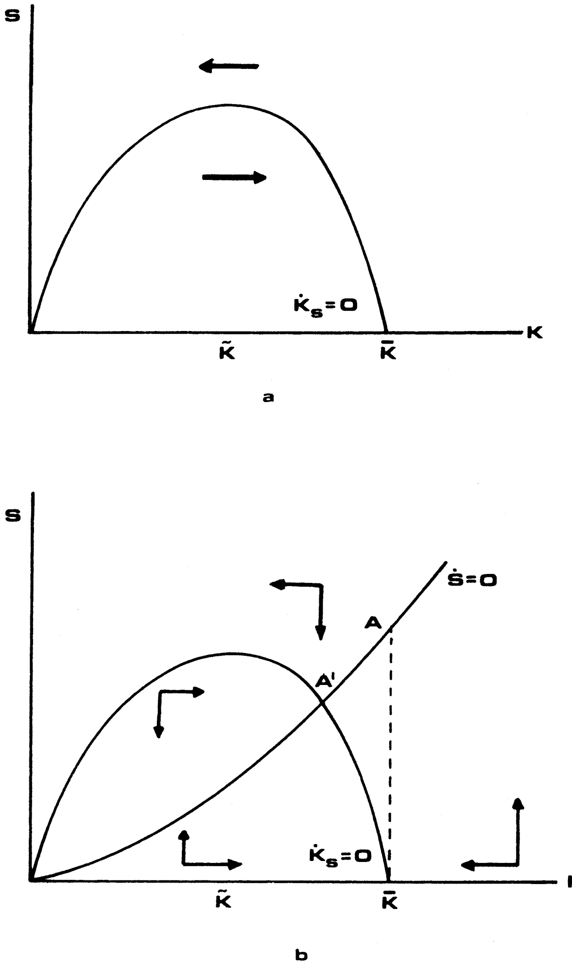

Fig. 16-5. Steady state with negative productivity effect

capital formation. As a consequence, the capital stock has to decrease above the $\dot{K}_S$ curve. Below the $\dot{K}_S$ curve, on the other hand, $sF\,(K,\,S) > \pi K$ holds because a smaller pollution pool allows a greater capital formation. The capital stock increases.

Figure 16-5b represents the phase diagram with four possible regions. In an economy characterized by the negative productivity effect arising from pollutants, situation A' is reached in the long run. This situation is stable, in the sense that in all four regions a stable path exists tending toward A'. Environmental disruption is again a consequence of economic growth. An unfavorable emission function (a shift of the $\dot{S} = 0$ curve upward) would cause a greater quantity of pollutants. Given a very strong increase in pollution intensity (upward shift of the $\dot{S} = 0$ curve), it is also conceivable that the greater pollution pool could have such a strong negative effect on output and capital formation that the pollution stock would be reduced in the long run (because of reduced capital accumulation).

Compare situation A in Fig. 16-4-a with A' in Fig. 16-5-b. The negative effect of productivity acts as a growth “brake”. In the long run, the economy reaches a smaller capital stock (and thus a smaller level of output). With a smaller capital stock, a smaller pollution pool also results.

The Survival Issue

In Fig. 16-5b the negative effect of productivity can be considered as a growth brake. By way of a *Gedankenexperiment*, let the negative productivity effect become more important, that is to let $\dot{K}_S$ increase in absolute terms. This will move point A' in Fig. 16-5b downward towards the origin, because the $F_S = 0$ curve shifts downward and to the left. Clearly, this would be an unfavorable effect severely limiting the possibility to accumulate capital and to produce. In Fig. 16-6a, the same effect is illustrated by a movement from A' to D[2].

Another unfavorable effect would be an increase in pollution per unit of capital, that is a larger Z', or a decline of the rate of assimilation, ·. These phenomena would shift the $\dot{S} = 0$ curve upward and to the left, implying more pollution with a given capital stock at a point D'. The combined effects will lead to a steady state D''.

If both effects keep operating, the economy would move towards the origin, suppressing economic activity. In that interpretation, the discussion can be viewed as a simple illustration of the survival issue. If some minimal capital stock is necessary for survival or if some level of pollution such as $\bar{S}$ in Fig. 16-6a cannot be surpassed, steady-state solutions such as D' or D'' may not be feasible.

Environmental Quality as a Normative Restriction for Growth

In the previous analysis, no environmental policy was undertaken. Assume now that in order to guarantee a certain environmental quality, normative restrictions for environmental use are introduced. Assume that the government introduces an emission tax. Then an incentive is established to build capital in abatement. This implies, however, that less capital is available for production. If K in Fig. 16-4b denotes the capital stock in production, for a given capital stock in production there are fewer emissions because a part of the gross emissions is abated. The $\dot{S} = 0$ curve shifts downward in Fig. 16-4b where the negative productivity effect is not considered.

The $\dot{K} = 0$ curve also changes its position. The gross national product must provide consumption, capital formation in abatement $\dot{K}_A$, and capital formation in production $\dot{K}_Z$. We have

[2] As a limiting extreme case, the curves could be suppressed to such an extent that the steady state would lie in the origin.

$$Q = C + \dot{K}_A + \dot{K}_Z$$

or

$$\dot{K}_Z = sF(K) - \dot{K}_A - \pi K \tag{16.5}$$

If capital is formed in abatement ($\dot{K}_A > 0$), the $\dot{K}_Z = 0$ curve shifts to the left. With the introduction of an emission tax (environmental policy), a smaller capital stock and a smaller quantity of pollutants result (situation A'' in Fig. 16-4b). A goal conflict exists between an improvement in environmental quality and economic growth. With environmental policy a smaller quantity of pollution comes about (and thus a better environmental quality), but this improvement is accompanied by a smaller capital stock and a smaller national product.

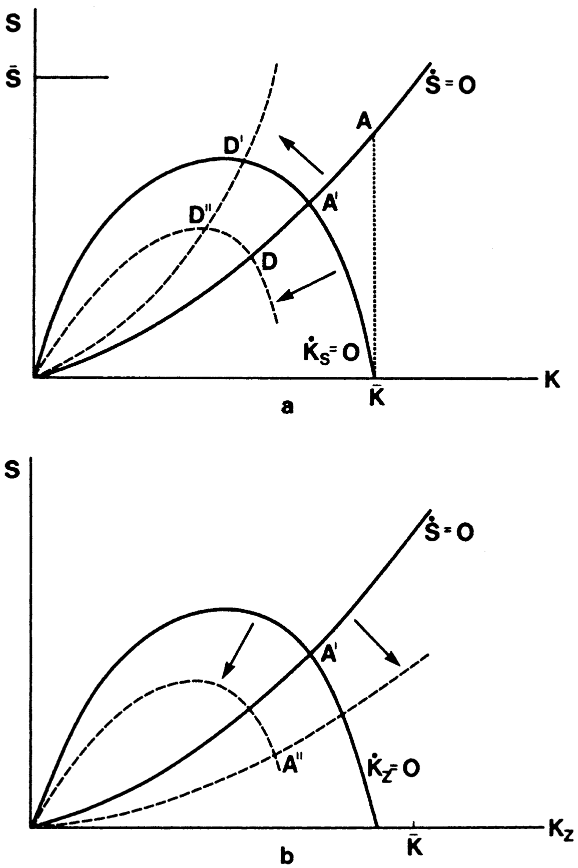

Fig. 16-6. Survival and environmental policy

In Fig. 16-6b, the influence on environmental policy in this case of the negative productivity effect is shown. Again, the $\dot{S} = 0$ curve shifts downward. The $\dot{K}_Z = 0$ curve shifts downward, too, so that the economy moves from A' to A'' reducing pollution at the cost of capital in production.

Optimal Growth

While in the previous considerations environmental policy was introduced exogenously, one can also imagine the maximization of a welfare function for a finite or an infinite planning period. Such a model would be presented by the approach employed in chapter 15 and should be extended by an equation of motion of the capital stock in production and abatement. Although this approach is quite complex (with three state variables and three shadow prices for the state variables), the basic result is a normative decision between environmental disruption and the level of the national product, in other words, between qualitative and quantitative growth.

Growth with Finite Resources

In the previous section, environment quality was regarded as a public-consumption good. The environment can also be viewed as a supplier of natural resources. The survival issue can now be placed into a wider context with the following constituting elements. Pollutants accumulate from production (or as a function of the capital stock) and depreciate with a constant rate α according to Eq. 16.1. Capital is formed by savings, and the capital stock depreciates at a rate π (Eq. 16.2). The resource withdrawal in each period influences the change in the resource stock

$$\dot{R} = f(R) - X \tag{16.6}$$

where $f(R) = 0$ holds for nonrenewable resources. A production function describes the dependency of the output on the inputs (labor, capital, and resource use X) for a given technology T:

$$Q = F(A, K, X, T) \tag{16.7}$$

In addition, there is some restraint on the production system due to environmental considerations. Moreover, the population may increase. The question then arises under which conditions growth or survival will be possible. Whereas growth implies an increase for instance in income per capita, survival is defined with respect to some minimum level of income or consumption.

Weak or Strong Substitutability

In considering the production function, the relevant question is whether the resource is "essential". If one cannot produce without the resource, that is, if $F(K, A, O) = 0$, then in the long run a situation cannot be maintained in which survival or growth are possible. The system will use up all resources in finite time and will collapse. A necessary condition therefore is that the resource is not strictly necessary for production, that is, if $F(K, A, O) > 0$. Then the resource is substitutable. An important distinction is that between "no", "weak" and "strong" substitutability (Pearce and Atkinson 1993). If substitutability is weak, it will put a stark restraint on growth. If can be easily substituted, the restraint is weaker.

If in a scenario of constant population technical progress is allowed to circumvent the resource scarcity issue, the problem remains how the environmental constraint will affect growth. It is no question that environmental constraints will reduce economic growth. Again, if enough technological progress is allowed, either in production or in abatement, growth is possible. If in addition we introduce population growth and at the same time want to guarantee survival (or growth) with giving due consideration to resource and environmental constraints, we must allow enough technological progress or sufficient adjustment in population change.

Growth with Human Capital

In growth models in which human capital plays a large role as a driving force of economic growth some of the above implications change. Instead of Eq. 16–3 consider a production function of the form

$$Q = F(K, H, S) \tag{16.8}$$

where H is human capital. If human capital has a high production elasticity economic growth will not be associated so intensively with environmental degradation; the assimilative capacity of the environment will not play the same role as a brake on growth as in the context of physical capital accumulation where pollutants are generated by capital accumulation, i.e. $S(K)$.

Thus, new growth theory suggests a different outlook. Especially if physical capital (or dirty inputs) can be substituted easily by human capital, the environmental restraint becomes less pressing.

Endogenous Growth

A similar result holds in models which endogenously generate technical progress as in the Romer (1986) or Rebelo (1991) type. This would be especially true if technical processes can be generated by which the emission intensity of production (or of physical capital) is reduced. The same statement holds for a lower resource intensity. Thus, the more emphasis is put on human capital and on new technical knowledge, the less important will be environmental restraints.

Building on Lucas (1988) and Rebelo (1991), Bovenberg and Smulders (1995) show that in a two-sector model permanent growth can be achieved if physical and human capital increase due to the optimal choices of actors. This result obtains if constant returns to scale in artificial (man-made) factors prevail and the condition of unitary elasticity of substitution between environmental quality and goods in the production and the consumption utility function holds. Then, technological growth can cause a decrease in the level of pollution per unit of output. Also, it can be shown that even with the incorporation of the scarcity of natural resources as a check on innovation, it is possible for consumption to be upheld for ever. However, over time, the economy will need to rely increasingly on innovation and conserve resources as natural resources are depleted (Barbier 1999).

Sustainable Development

The concept of sustainable development was born in 1980 when the International Union for Conservation of Nature and Natural Resources developed a conservation strategy with "the overall aim of achieving sustainable development through the conservation of living resources" (Lélé 1991). The concept then was taken over by the World Commission on Environment and Development (1987, p. 49): "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' The concept was widely recognized through its use in the Brundtlandt report (1987).

The term "sustainable development" is only defined in broad terms, it has been denoted as a "notional handrail" (Holmberg and Sandbrook 1993, p. 23). Sustainable development "is in the real danger of becoming a cliché – like appropriate technology – a fashionable phrase that everyone pays homage to but nobody cares to define" (Lélé 1991, p. 607).

Opportunity Costs for the Future. The concept of sustainable development gives prominence to the intertemporal aspect of economic activities and their impact on the environment and the resource base in the future. Thus, opportunity costs for the future are at the center of the concept. Sustainable development is related to the concept of optimal growth in which a balance between economic growth and environmental degradation is sought. In optimal growth, the well-being of future generations is explicitly taken into account. Thus, the opportunity costs of environmental pollution and of resource use today play a role, and in this way, there is a price tag today for damaging the environment for future generations and for using the resource base. Problems arise how these opportunity costs can be specified.

Social Impacts. A first distinction among the concepts is whether social impacts (poverty, social disruption) are explictly part of the concept. This means that distributional issues at a given moment of time as well as problems of social (and possibly political) stability are part of the concept.

Growth or Development. A second distinction is whether the concept relates to economic growth or economic development where growth supposedly is a narrow concept. Then, the term sustainable economic growth is used to mean that "real GNP per capita is increasing over time and the increase is not threatened by "feedback" either from biological impacts (pollution, resource problems) or from social impacts (poverty, social disruption)" (Holmberg and Sandbrook 1993, p. 22). In this interpretation, environment and nature are interpreted as a restraint for economic growth. The concept attempts to preclude negative growth, and more specifically it precludes economic growth today at the cost of growth in the future. By defining growth over a long time horizon, factors normally not included in the definition of growth such as environmental conditions enter into the growth concept.

Total Wealth or Natural Wealth as Restraint. A third distinction is whether sustainability relates to a restraint on all assets including man-made assets or not. One concept according to Pearce, Markandya and Barbier (1989) is that per capita utility or well-being is increasing over time with substitution between natural and man-made capital. In this interpretation, the concept of sustainable development attempts to assure a given (or improved) standard of living to all future generations. The idea is that a given quality of life should not be lost. Standard of living is to be interpreted in a wider meaning including income per capita as well as environmental conditions.

This concept requires that the total stock of resources – including exhaustible resources, environmental resources, physical and human capital – does not decrease over time in its production capacity. Future generations should inherit a stock of resources where physical capital, environmental capital and the resource base can be substituted. Substitution gives flexibility in the system. Keeping the resource base per se is not necessary. Sustainability depends on the production capacity of resources. Thus, technological knowledge may be instrumental in allowing sustainability. Again, sustainability requires the signalling of the "right" scarcity to the economic system with prices reflecting future scarcity conditions.

A still narrower concept is "that per capita utility or well-being is increasing over time subject to non-declining natural wealth" (Holmberg and Sandbrook 1993, p. 22). This precludes substitution of different types of assets, e.g., natural wealth must be upheld in a narrow interpretation ("strong" sustainability). The environment and nature as capital goods assets should be not degraded. The answer here is that future environmental damages should be reflected in the scarcity prices today. If a pollutant accumulates over time its negative shadow price should signal future damages (chapter 15).

Expressing Assets as a Constraint. It is a complicated matter to adequately express assets or wealth defined for future generations as a constraint for the present generation. One approach is to express natural wealth in non-pecuniary terms, i.e., in physical quantities such as indices of pollutants ambient in the environment or of bio-diversity. This raises the issue of a multitude of dimensions in various criteria, which are difficult to aggregate into one criterion. Man-made wealth has to be aggregated by prices, and in principle, environmental and natural wealth should be aggregated by prices, too.

Substitutability. Whether natural resources and environmental quality can be substituted by other factors of production, is central to the issue of sustainability. If a resource is not essential for a growth process, economic activity can do without it and the production set is less severely restricted.

Human Capital. If besides physical capital and labor, human capital is explicitly introduced as a factor of production, sustainability becomes less of a concern. This holds if physical capital and natural resources can be substituted by human capital assuming human capital does not negatively affect the environment.

Technical Progress. When new technical knowledge is generated endogenously in the process of economic growth emission-intensive production activities may be substituted by cleaner activities. The resource intensity may be reduced.

Uncertainty. A risk exists that life supporting systems or environmental assets will be destroyed. If these assets are essential, a preventive environmental policy is required (see chapter 15). If technical progress in abatement technology is strong, substitutability may be enhanced and the problem may be less severe.

Irreversibility. Irreversibilities affect the living conditions of future generations. Here the answer is that an option value should be used in the evaluation of decision alternatives if an option of use is irreversibly lost (see chapter 17). An option value indicates benefits lost or opportunity cost for future generations. Uncertainties on future states of the world would increase the option value lost today.

Time Horizon and Discount Rate. An unresolved question in the definition of sustainable development is to which time horizon the concept of sustainable development should apply. Should it be a finite time horizon? Or should the concept relate to infinity? Here the discount rate is relevant. The discount rate determines which weight the benefit of future generations will have in today's decisions. A high discount rate implies a greater weight for present generations. Thus, a low social discount rate would give more weight to the interest of future generations. In growth models, the interest rate is linked to the real growth rate. Then, the appropriate social discount rate is given by the growth potential of the stock of man-made and environmental assets along a sustainable development path. The issue is how high the sustainable interest rate is. Note, however, that signalling the right environmental and natural scarcity through prices implies that the interest of future generations is respected.

Trade and Sustainability. In a context of sustainability where substitution of natural resources is possible (weak sustainability), a country can import sustainability by importing natural resources or by exporting wastes (Klepper and Stähler 1997). Thus, a country can circumvent the limits given by exhaustion of natural resources (or of assimilative capacity) by trading its traditional exportables against natural resource imports or against exports of wastes. If natural resource availability (and assimilate capacity) differs among countries, trade will have a tendency to average out resource scarcities in the long run among countries and confront each country with similar sustainability problems (assuming identical preferences). For the representative country, all the aspects discussed here with respect to sustainability remain.

Zero Economic Growth

Besides sustainable development, some ecologists have demanded zero economic growth as a solution to the goal conflict between economic growth and environmental degradation. Zero economic growth has to be evaluated by two criteria: First, what kind of opportunity costs are caused by zero growth? Second, can zero growth be a suitable measure to reduce pollution and the depletion of natural resources?

Opportunity Costs of Zero Economic Growth

A growth stop has a number of undesired effects. First, economic growth makes it possible to increase the supply of goods, and while such an increase may not seem urgent for several richer nations, it is an absolute necessity for the countries of the Third World. As a result of medical progress, life expectancy in these countries has been increased while birthrates remain high. These countries have only a small industrial base and are afflicted with immense poverty, for instance, a yearly per capita income of $400 in some cases. For these countries, zero growth would mean economic and political chaos.

Second, slower economic growth in industrialized countries would adversely affect the developing countries. Their export chances would fall, and employment and national income would decrease. The economic situation of countries in the Third World would necessarily worsen if the industrialized economies experienced slower growth. Also, a solution to the international distribution problem would become rather difficult.

Third, with slower economic growth, the industrialized nations would also be significantly affected. Although there is no stringent link between growth and employment, there are some points in favor of the thesis that full employment is at least more easily achieved in a growing economy.

Fourth, with slower economic growth, the supply of public goods such as education and training, housing, hospitals, and medical care would be very much impaired. Social services provided by the state, especially old-age pensions, would be jeopardized.

Fifth, growth implies a moderation in the conflict over income distribution and a reduction of tension in society. A relative redistribution of income can be achieved much better in a growing economy than in a stationary one. During the 1960s and 1970s Great Britain exemplified the internal distribution problem which a country encounters during a period of decreasing economic growth. Slower growth accompanied by increasing distribution conflicts can cause the rate of inflation to rise. Further, deficits in the balance of payments become likely.

Sixth, economic growth and environmental protection are not mutually exclusive for yet another reason. Environmental protection demands new production technologies that are favorable to the environment. It demands large investments in order to abate the waste arising from consumption and production and to promote the recycling of materials. Environmental protection may stimulate a number of very important growth factors and thereby prompt the economy to move in a new direction of development.

Environmental Effects of Zero Economic Growth

If the opportunity costs of zero growth are judged to be less severe, the question remains of whether zero growth has the desired effects on environmental quality and on the conservation of natural resources. Let us first consider what the effects of economic growth would be assuming that the environment is used as a common property free of charge. Then we know that increasing production raises the quantity of pollutants. The pollution-intensive sector is expanded too much with respect to the less pollution-intensive sector. The distortion of the sectoral structure implies a greater accumulation of pollutants. The zero price of environmental use does not provide any incentives to use resources in abatement, to develop new abatement technologies, or to look for more emission-favorable production technologies. The accumulation of pollutants reduces environmental quality; that is, quantitative growth with a zero price attached to environmental use leads to a negative qualitative growth. Finally, with a zero price, natural resources are overused; that is, too small a stock of resources is passed on to future generations.

Although economic growth influences environmental quality when there is a zero price assessed for environmental use, we cannot draw the conclusion that zero growth would be an appropriate measure by which one could achieve a better environmental quality and smaller depletion of resources.

Zero growth does not change the actual level of economic activities; thus, environmental pollution remains fixed at its given level. Zero growth does not even prevent a further deterioration of environmental quality; pollutants are still released into the environment and accumulated there. Environmental quality, then, can decline in spite of zero economic growth. Furthermore, zero growth does not imply that we would use resources more economically.

The relevant issue is not whether growth intensifies the conflict between the supply of goods and environmental quality, but rather the way growth has taken place previously. The structure of national output and the relationship between pollution-intensive and environmentally favorable production causes this conflict of objectives. As stated in chapter 2, the free use of the environment is the basic reason for environmental degradation. The environment cannot be used any longer as a free good for all competing uses. Instead, these competing uses must be evaluated, and the use of the environment allocated to those activities offering the highest merit.

If the zero price of environmental and resource use is abolished, the following consequences will ensure: There will be an incentive to use factors in abatement so that production will be reduced and thus emissions decrease. The emission tax will cause a sectoral reallocation which disfavors the pollutionintensive sector and thus reduces emissions (improvement in environmental quality). We have the incentive to accumulate capital in abatement and to develop new abatement technologies. An incentive exists to use emissionfavorable technologies in production. Finally, correcting the prices of natural resources implies that fewer resources will be demanded because of, for example, substitution by "cheap" raw materials or recycling. When the proper price of environmental use is taken into account, a set of adaptations takes place which improves environmental quality. The goal conflict between growth and environmental quality may be altered if these adaptations are considered. Thus, pollution and growth can be uncoupled by the right incentives. This gives a different interpretation to the term "growth". It no longer means economic growth only, but environmental degradation is taken into account.

An Optimistic Note: The Environmental Kuznets Curve

Simon Kuznets (1955) has made an empirical observation on the relationship between inequality and per capita income. According to his observation, inequality is low when per capita income is low, and then rises with per capita income. From some threshold on, inequality falls again. Similarly, it is hypothesized that pollution rises with an increase in income per capita due to industrialization, but then eventually will fall with a higher income level (Figure 16-7). The reason for this is that new technologies are applied that reduce emissions and that abatement activities are initiated. Pollution and growth then are characterized by an Environmental Kuznets Curve (Stern 2003). Let emissions per head s be a linear function of output per head y and assume that the function h itself depends on the level of output per head. Then

$$s = hy \tag{16.9}$$

$$h = a - by \tag{16.10}$$

From this we have

$$s = (a - by)\, y = ay - by^2. \tag{16.11}$$

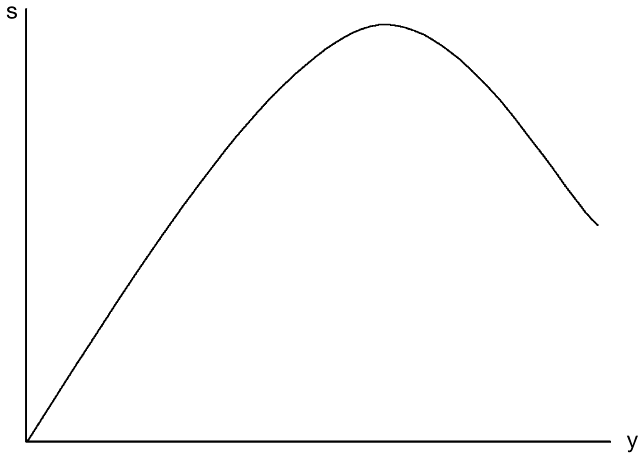

Fig. 16-7. Environmental Kuznets Curve

This hypothesis is a rather coarse view of the relationship between pollution and growth. It is based on a change in technology and in environmental policy with rising income, but it cannot define away the issue of specific scarcities of resources or the negative impact of pollution on growth, if the technology is given. Empirically, the relationship is indeed found for some pollutants (Perman et al. 2003:36), but is increasingly questioned whether this stylised fact of environmental economics does hold. A panel data set of sulfur emissions and GDP data for 74 countries over a span of 31 years shows that the data is stochastically trending in the time-series dimension (Perman and Stern 2003). Another paper finds that the results are highly sensitive to changes in such variables as nations, cities and years sampled (Harbaugh et al. 2002). It has also been suggested by empirical analysis that the curve is actually flattening and shifting to the left due to economic liberalization, clean technology diffusion and new approaches to pollution regulation in developing countries (Dasgupta et al. 2002). Endogenous growth would generate a different curve whereby the level of pollution actually falls with a rising per capita income.

17 Risk and Environmental Allocation

The frame of reference of our analysis of environmental use so far was a world of certainty. The fabrication of pollutants as a function of consumption and production, the accumulation of pollutants in the environment, and their impact on environmental quality all were recognized with certainty. In reality, quite a few of the basic functions describing the role of the environment are not well known "ex ante." Emissions interact through rather complex and intricate systems and pollutants such as DDT accumulate through natural chains in a way that often is only discovered "ex post" with some delay. Variables strategic for the analysis of environmental allocation can therefore be considered as random variables. Pollutants as a by-product of our economic activities include the risk of potentially generating negative environmental impacts in the future. Risk of environmental effects may relate to small-scale issues such as the eutrophication of a pond or to global problems as the heavily debated greenhouse effect from an increase in carbon dioxide or the destruction of the ozone layer. The problem arises what types of risk exist in using the environment, how these risks will influence environmental use if some optimal environmental quality is strived for, what implications will follow for environmental policy instruments, and how the costs of risk reduction should be allocated to the decentral subsystems of a society.

Environmental Risks

Risk means that the implications of a decision cannot be fully determined "ex ante." Variables or interdependencies affecting a decision are random, i.e., the occurrence of a specific value of a variable depends on a state of nature which cannot be controlled by the agent. Variables strategic to the problem of environmental allocation such as assimilative capacity, the stock of accumulated pollutants, environmental quality in a given moment of time, or emissions diverge from a mean on both sides with the mean being defined as the expected value of the mathematical variance of possible results. Normally it is assumed that an agent can attribute probabilities to a variety of outcomes, i.e., the agent knows a density function for the random variable.

Attitudes toward risk may vary between individuals. People may be risk averse, risk neutral, or risk lovers. Consequently, a given probability distribution or (assuming a normal distribution) a given variance in a specific variable may not imply the same risk for different agents. Moreover, if all agents were to have the same risk attitude, the probability distribution of a specific variable may be relevant to one agent, but not to the other. Consequently, risk can only be defined with respect to the objective function and the restraint set of a specific agent. The risk that is specific to the objective function and the restraint set of an individual agent is called private risk. This type of risk is not correlated across persons and is also labeled independent risk (Dasgupta 1982, p. 81). If, however, a public good is a random variable we speak of social risk. Then the risk is correlated across persons, that is the risk is dependent. By definition, pure social risk must relate to all agents in the same way. Private risk can be shifted to another agent if he/she is willing to take over that risk possibly because a given probability distribution does not influence the target all that negatively or even positively for him/her. Social risk, however, cannot be shifted.

In the case of the environment, different types of risk relating to the different roles of environment can be distinguished. There is uncertainty with respect to the accumulation, the interaction, and the spatial transport of pollutants. This type of risk relates to the diffusion function or to variables in the diffusion function. There is also uncertainty with respect to damages of a given quantity of pollutants. The magnitude of damages may not be known or the time when the damage arises may be undetermined. A specific problem may arise if threshold effects prevail and if the properties of these threshold effects cannot be determined "ex ante." Similarly, there may be the risk that a specific type of environmental use is irreversible. Other risks relate to the assimilative capacity of the environment or the generation of pollutants from consumption and production. Thus, risk may exist with respect to the occurrence of emissions when pollutants are not generated continuously in a regular pattern but at random as in accidents (Seveso, Bhopal, Sandoz). Costs of abatement as well as production technologies may not be known "ex ante."

We are here mainly interested in the risk of environmental degradation for society as a whole where the environment is treated as a public good. Some risks in the area of environmental use may, however, be defined for specific agents. For instance, in the interpretation of the new political economy, the policymaker with the objective of being reelected faces the risk that the preferences of individuals with respect to environmental quality shift and that he/she may not have correctly anticipated the preference changes of individuals. The individual polluter, i.e., a firm, is exposed to the risk that he/she will be held liable for the pollution caused or that environmental policy instruments will vary over time.

In our analysis of environmental allocation we have stressed that the role of the environment as a consumption good relates to the public goods aspect whereas the environment as a receptacle of waste is a private good. Consequently, all risks referring to the public goods aspect of the environment are social risks where risk shifting is impossible and where the appropriate approach is risk reduction. The costs of risk reduction, however, can be attributed to those who use the environment as a receptacle of waste.

In the discussion of the environment as a public good the free rider is a central issue. This problem also arises in the case of social risk when the probability distribution or (assuming a normal distribution) the variance in a variable representing a public good has to be evaluated. In this context, risk attitudes come into play. The risk attitude of a society can be considered as the aggregation of the risk attitudes of its individual members. Thus, determining the risk attitude of a society poses similar problems as establishing the time preference rate.

In addition to the aggregation of given individual risk attitudes, the perception of uncertain phenomena plays a decisive role for the aggregation problem and for policy making. Perception of uncertain phenomenon by a specific agent depends on his/her information and consequently on the distribution of information in society, so that the question arises of whether perceptions and beliefs should be aggregated in the same way as individual preferences or whether time should be allowed for information to spread and for perceptions to change. Then, optimal allocation of risk should be based on ex post and not on ex ante perceptions (Dasgupta 1982, p. 70).

Risk and Environmental Quality

From a policy point of view, uncertainty relates to the impact of pollutants on environmental quality. A simple way to introduce risk is to interpret assimilative capacity in each period $\tilde{S}^a$ as a random variable being identically and independently distributed over time. Alternatively, risk may be introduced into the damage function

$$U = G(S, \tilde{\theta}) \tag{17.1}$$

so that environmental quality U becomes a random variable depending on the stock of pollutants and on states of nature $\tilde{\theta}$. Equation 17.1 can be simplified by assuming either that risk is additive

$$U = G(S) + \tilde{\theta} \tag{17.1a}$$

or that risk is multiplicative

$$U = \tilde{\theta} G(S) \quad \text{with} \quad \theta \leqslant 1 \tag{17.1b}$$

and G_S, $G_{SS} < 0$. Introducing randomness into a variable of the constraints in a maximization problem implies that the target variable itself becomes a random variable so that the policymaker maximizes the expected utility of the target variable subject to the constraints. Note that in Eq. 17.1 b risk is assumed to be distributed identically and independently over time.

Assume that social welfare W depends on a private good Q and on environmental quality U. For simplifying purposes only one private good is considered. The welfare function is assumed to be well-behaved.

$$W = W(Q, U) \tag{17.2}$$

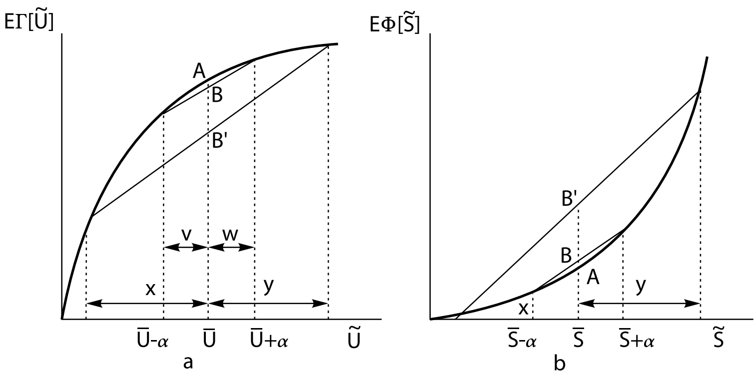

Fig. 17-1. Expected utility and disutility

In order to model risk attitudes in the interpretation of the expected utility theory, let Γ denote a utility function indicating risk attitudes of society. Then the expected utility of social welfare in any given period is $E\Gamma[W(Q, U)]$.

The country is risk averse if $\Gamma' > 0$, $\Gamma'' < 0$. According to the expected utility theory the risk averse country chooses a linear combination of the possible outcomes. Thus, the country chooses the expected utility of welfare at point B instead of point A in Fig. 17-1a if the spread is a around the mean $\bar{U}$ and if the states $\bar{U} - \alpha$ and $\bar{U} + \alpha$ both have the probability 0.5. Consider now a mean-preserving spread in the random variable $\tilde{U}$, i.e., a stretching of the probability distribution around a constant mean. Then the country will choose point B' instead of B. Thus, an increase in the spread will reduce $E\Gamma\,[W(U)]$ for a given U.

Due to Eq. 17.1 b expected disutility can be expressed as a function of the stock of pollutants S. Expected disutility of a stock of pollutants increases progressively with S due to G_S, $G_{SS} < 0$. A risk-averse agent will again choose a linear combination of possible outcomes such as point B in Fig. 17-1b. A mean-preserving spread in assimilative capacity or in θ will increase the expected disutility of pollutants (point B' instead of point B in Fig. 17-1b). Thus, a mean-preserving spread definitely decreases expected utility of welfare from environmental quality (and increases expected disutility of welfare from pollution).

An intuitive interpretation of environmental risk is illustrated in Fig. 17-2 where DD is the marginal damage function and CS_0 the marginal cost function. An increase in environmental risk, i.e., a greater variance in the damages of a given level of emissions, implies an upward shift of the marginal damage function. Optimal environmental quality increases, i.e., it is optimal to abate S_0S' of emissions instead of S_0S. Emissions now have a higher price tag. The same result is obtained when a country becomes more risk averse. Then, the damage function shifts upward as if pollution had become more risky.

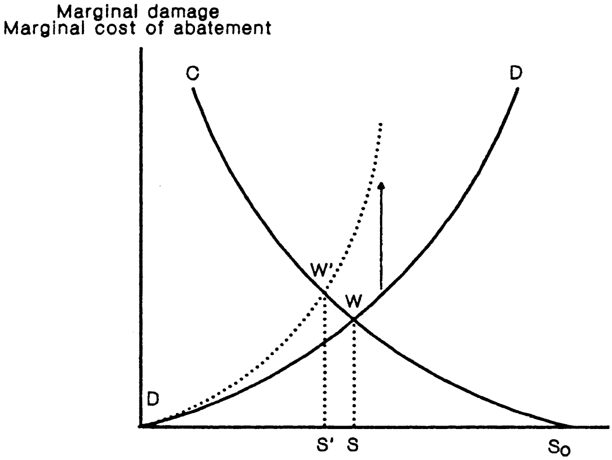

Fig. 17-2. Increased risk and optimal environmental quality

A Simple Static Model

Applying the risk concept of Eq. 17.1a to the model of chapter 4 and simplifying that model yields the following static maximization problem.

$$\text{Max}\, E\{W(Q, U)\}$$

subject to

$$\begin{aligned} U &= G(S) + \gamma\theta \\ S &= H(Q) - F^r(R^r) \\ Q &= F(R) \\ \bar{R} &= R + R^r \end{aligned} \tag{17.3}$$

where $f(\gamma\theta)$ is the density function and y is the mean-preserving spread. We neglect risk aversion. The Lagrangean function is

$$\begin{aligned} L = \int & W[F(R),\, G(S) + \gamma\theta] f(\gamma\theta) \\ & - \lambda[H\{F(R)\} - F^r(R^r) - S] \\ & - \mu[R + R^r - \bar{R}] \end{aligned} \tag{17.4}$$

The optimality conditions are

$$\frac{\partial L}{\partial S} = \int W_U G_S f(\gamma\theta)\, d\theta + \lambda = 0 \tag{17.5a}$$

$$\frac{\partial L}{\partial R} = \int W_C F_R f(\gamma\theta)\,d\theta - \lambda H_Q F_R - \mu = 0 \tag{17.5b}$$

$$\frac{\partial L}{\partial R^r} = \lambda F_R^r r - \mu \tag{17.5c}$$

This yields a condition for the shadow price on emissions

$$\begin{aligned} -\lambda &= \int W_U G_S f(\gamma\theta)\,d\theta \\ &= \int W_C F_R f(\gamma\theta)\,d\theta / (H_Q F_R + F_R^r r) \end{aligned} \tag{17.6}$$

Note that due to $dR = -dR^r$,

$$H_Q F_R + F_R^r r = -\frac{dH}{dR^r} + \frac{dS^r}{dR^r} = \frac{d\tilde{S}}{dR^r}$$

which is the net reduction of emissions by using one unit of the resource for abatement. Net reduction comes about by reducing emissions directly in abatement and withdrawing the resource from production. Then $d\tilde{S}/dR^r$ denotes the net productivity in abatement and $1/(d\tilde{S}/dR^r)$ is the first derivative of the inverse function $\tilde{S} = k(R^r)$ which is the net input requirement function. Thus, the term $1/(H_Q F_R + F_R^r r)$ denotes the marginal input requirement, and the first term on the right-hand side of Eq. 17.6 is the marginal value of resources used. Thus, the right-hand side of Eq. 17.6 denotes marginal abatement cost. The left-hand side is marginal damage. The shadow price for emissions must be set in such a way that marginal damage and marginal cost of abatement are equal. As in the intuitive interpretation of Fig. 17-2, the damage curve is effected by the existence of risk. Note, however, that the risk term also appears in the term on marginal cost of abatement. This is due to the fact that in the utility function, marginal utility of consumption also depends on environmental quality. With environmental quality being a random variable, the marginal utility of consumption is a random variable as well. If we assume a separable utility function, the marginal utility of consumption is not affected by the environmental risks. Then Fig. 17-2 holds.

Risk in an Intertemporal Context

In the maximization problem of Eq. 17.3 risk was introduced in a static allocation context. A more demanding task is to introduce risk in a dynamic context. This would mean to rewrite chapter 15 under the conditions of risk. In such a context, the policymaker maximizes the present value of expected utility from the welfare of society

$$\int_0^\infty e^{-\delta t}\{E\Gamma[W(Q,U)]\}dt \tag{17.7}$$

subject to Eq. 17.1b and the constraints in chapter 15.

One possible approach is to interprete a variable of the problem in each period as a random variable being identically and independently distributed over time. For instance, environmental damages or assimilative capacity may be such a variable.

The problem with this approach is that it can be used in a two-period (or multiperiod) Lagrangean maximization problem, but control theory cannot be applied because an important condition, that the integral to be maximized must be differentiable, is not given.

The alternative approach is to use the Ito theorem and to model intertemporal risk as a Wiener process consisting of a trend and some noise. For instance the time path of the stock of pollutants may be written as

$$dS = S^P(Q)dt - S^r(R^r)dt + \sigma dz \tag{17.8}$$

where dz stands for a Wiener process.

Alternatively, risk may be modelled as a jump process in which one state of nature abruptly changes into a new state. This can be modelled in terms of a Markov process with transition probabilities.

In the following analysis, we will limit ourselves to a verbal and intuitive discussion of the problem of environmental risk in an intertemporal context. Admittedly, this analysis is highly speculative. How does environmental allocation change if relative to a situation of certainty risk is introduced?

We start from the intertemporal analysis of environmental allocation and Fig. 15-2. If we now allow for more environmental risk, for instance in possibly higher damages for a given level of pollution, we should expect that the penalty on emissions has to be increased. We can expect that in order to take into account the increased future risk, a lower level of pollution S^{**} will be optimal.

With more risk in the damage function, the time profile of the shadow price has to change if the initial level of pollution $S(0)$ is to be transformed into the new steady state S^{**}. The penalty for pollution will be higher initially as well as on the way to the steady state. In any given period before the steady state, the shadow price (in absolute terms) will be higher forcing the economy to generate less pollution. Thus, an increased uncertainty in the damage function can be expected to imply a lower level of pollution.

The result depends on the assumption that increased uncertainty of environmental damages will increase the expected marginal disutility of pollution (for a given level of pollution) and that thus the $\dot{\mu} = 0$ curve is shifted upward. The result is that the planner has an incentive to reduce the increased risk of environmental quality by just having a lower environmental quality.

An increase in risk aversion of the policymaker should shift the curve of expected disutility in Fig. 17-3 upward, and thus will shift the $\dot{\mu} = 0$ curve

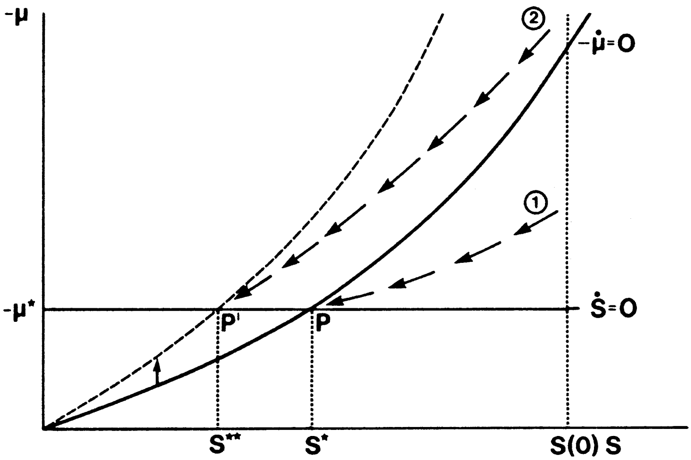

Fig. 17-3. Risk in the damage function and steady state

upward. Consequently, if the uncertainty in the damage function remains unchanged and if risk aversion is increased, the steady state shifts to the left implying a Pontryagin path with a higher penalty on emissions.

Assume now that the risk of the assimilative capacity in each period is increased, by a mean-preserving spread with more weight in the tails of the distribution, whereas $\tilde{\theta}$ is set equal to one. How will the steady state and the optimal path from a given initial level of pollution be affected?

We assume that the marginal expected disutility of a given level of pollution will be increased if there is more risk in assimilative capacity. Then, the $-\dot{\mu} = 0$ curve should shift upward; this implies that the steady state P moves to the left (point P') in Fig. 17-4. Moreover, for $S = 0$, fewer emissions are required for a greater uncertainty in the assimilative capacity. This is only possible, if the shadow price $-\dot{\mu}$ rises. The $S = 0$ curve shifts upward. The steady state shifts from P to P'''.

Preventive Environmental Policy

Figures 17-1 and 17-3 illustrate the concept of preventive environmental policy (O'Riordan 1985). With the environmental impact of pollution being uncertain, a higher environmental quality is optimal in the steady state. In order to reach less pollution in the long run, a higher penalty has to be put on pollution. Thus, environmental risks make the environment more scarce. Higher environmental quality can be interpreted as an insurance against the risk of environmental degradation or as a risk premium.

Note that preventive environmental policy varies with the risk aversion of the policymaker. If he is very risk-averse, he will ask for a low level of pollution

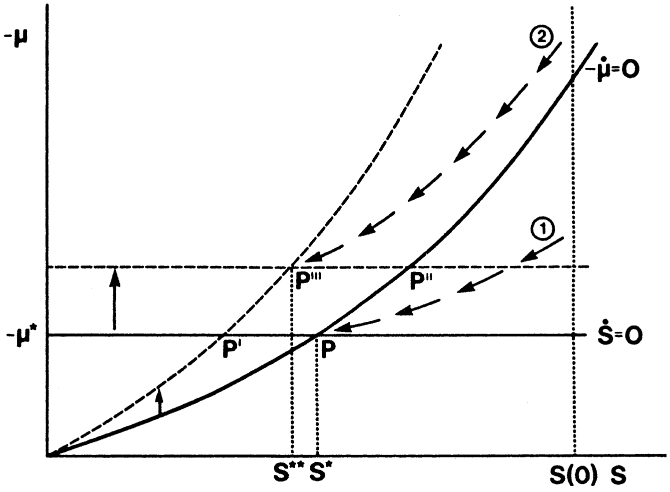

Fig. 17-4. Risk and steady state

as an insurance against the risk of environmental degradation. The costs of environmental protection will be relatively high, and they will vary with risk aversion.

Preventive environmental policy also depends on the discount rate. Future disutilities are discounted thus having a lower weight in the present value of expected welfare. Therefore, the present value of welfare can be increased if the disutilities are postponed into the future, that is if a unit of pollution is accumulated at a later date. As in the case of certainty, a higher discount rate implies a lower environmental quality.

Irreversibilities and Option Values

An important aspect of environmental risks are irreversibilities. When uncertain negative effects on the environment can be remedied in the future, risks may not be such a pressing problem. We only shift the costs of restoring or improving the environment to future generations. This still holds when the costs of restoration are very high. In the case of a pure irreversibility, however, the costs to remedy a negative environmental impact are infinite. Apparently there exists a continuum of restoration costs between zero and infinity.

Environmental risks represent a serious problem if restoration costs are infinite, that is if pure irreversibilities prevail. Examples are the extinction of a species or the destruction of a landscape that cannot be restored. Krutilla and Fisher (1975) have exemplified the problem with the Hells Canyon case where a Canyon is given up for a mine. Henry (1974) has discussed the problem of irreversibility with the example of turning Notre Dame in Paris into a parking lot.

Pure irreversibilities give rise to the question whether future benefits should be discounted. One solution to the problem is to use a lower discount rate, thereby giving more weight to the opportunity costs of the future. As an extreme case, if an irreversibility is judged to be crucial, a zero discount rate has to be applied. An alternative solution of handling irreversibilities is to explicitly introduce an option value being defined as the value, in addition to expected consumer's surplus from actually using a good, that arises from retaining an option to a good or service for which demand is uncertain (Krutilla and Fisher 1975, p. 70). For a risk-averse agent, the option price, i.e., the willingness to pay for keeping up an option, exceeds the expected consumer's surplus. Thus, the option value can be interpreted as an insurance premium or a risk premium against the irreversible loss of an alternative. Since the environment is a public good, the willingness to pay for an option cannot be determined by the market but must be established by other processes such as voting.

The concept of option value allows to introduce a specific value for avoiding an irreversibility. Note, however, that the debate on the discount rate or on the weight to be given to future generations cannot be completely separated from the determination of the option value. The option value will be affected by the discount rate.

If with the passage of time new information becomes available on the benefits and costs of a specific environmental use (Arrow and Fisher 1974), the relevance of irreversibilities will only come to light over time. Consequently, there is a positive option value even if the policymaker is not risk-averse.

Allocating Environmental Risks?

What institutional setting should be chosen in a society for the allocation of environmental risks and for the allocation of the costs for risk reduction? As an extreme answer to these two problems we perform a *Gedankenexperiment* and assume that exclusive property rights for the environment can be clearly defined so that the free rider does no longer exist. By this assumption, the environment has become a private good and environmental risks are no longer social risks. Assume bargaining costs and other transaction costs are zero. Assume also that the agents have objective probabilities for the occurrence of specific states of nature. Then a Coase theorem (1960) should hold for a world with environmental risk where risk allocation will be optimal in the interpretation of Coase. Externalities relating to risk are perfectly internalized and the Coase theorem can be interpreted as the analogon to the Modigliani-Miller theorem (1958) for a world of environmental allocation. Stochastic phenomena would be transformed into deterministic market values.

We know that in the case of environmental risks such a situation cannot hold. Property rights cannot be clearly defined because the environment is a public good and not all facets of the public good can be taken away by specifying exclusive property rights. Transaction costs prevail. As a matter of fact, in an institutional setting with private property rights, transaction costs can be expected to be rather high. One aspect of transaction costs in the case of uncertainty would be liability arrangements with reliance on the judicial system. The increased role of courts would imply an ex-post allocation of risk and would give rise to a large uncertainty in private decisions. Thus, it is rather unrealistic to assume that environmental risks can be efficiently allocated through a Coase type scenario.

The risk of environmental degradation cannot be shifted because by definition the environment is a public good and the risk of its degradation is a social risk. The appropriate policy therefore is risk reduction.

Risk Reduction

The approach of the previous sections presents a rather general and broad solution to risk, namely to establish a higher environmental quality which can be interpreted as an insurance or a risk premium against uncertain environmental degradations. This approach of risk management may prove to be rather coarse and rough in the sense that a more detailed analysis of the risks envolved may allow to reduce the risk in a more sophisticated way. Consider for instance the case where environmental quality is measured by an index of several pollutants in different environmental media. Then preventive environmental policy requires that all pollutants are reduced in the proportion of their weight in the index. Apparently, risk management could be improved considerably if information would be available on the specific impact of different pollutants in different media. Research on the environmental impact of pollutants may increase information and thus reduce uncertainty.

A more detailed analysis of environmental risk would attempt to model these risks more specifically. An important aspect are the worst case scenarios which have a rather low probability of occurring, but would have tremendous negative impacts. An approach here is to cut off these cases that are truncating the probability space. Of course, such an approach would depend on the costs involved. As an alternative approach, offsetting options for the worst case may represent an insurance premium. Other aspects of a more precise modelling of environmental risks are the consideration of irreversibilities (see above) and restoration costs where applicable, as well as the postponement of damages into the future (excluding irreversibilities) in the sense of diversification over time. Also a regionalization of public bads may be considered. For instance a hot spot policy, though in conflict with equity consideration, implies some type of spatial risk management concentrating risk in some areas and keeping risk away from other areas.

Allocating the Costs of Risk Reduction

An important aspect of environmental risk management is how the costs of risk reduction are allocated to the agents causing the risks. In contrast to natural hazards such as earthquakes an important ingredient of environmental risks is man made, namely pollutants. Thus, one strategy of risk reduction is to attribute the costs of reducing the social risks to the decentralized units of the economy. By efficiently allocating the costs of risk reduction to those decentralized units that cause the social risk in the first place, an incentive is introduced to reduce the social risk. Here the results on the use of environmental policy instruments as discussed in chapter 8 hold. If the environment can be used free of charge as a receptacle of waste, no incentive is introduced to reduce emissions. If emission taxes, other pricing instruments for emissions and other policy instruments are applied, in a rather general way some of the social risk of environmental degradation is reduced. Thus, in a world with risk, we have to make use of the polluter-pays principle; it requires that the costs of risk reduction should be attributed to the polluter.

The issue is to find not only an institutional mechanism that allows to attribute the costs of reducing environmental risks but also a mechanism that can be flexibly adjusted to new environmental situations coming to the foreground if damages are reversible. Which instruments should the regulator choose that allow a quick response to environmental degradation (Dasgupta 1982, p. 81)? When the attribution of social risks cannot follow flexibly to the arising of new damages or risk, i.e., when environmental policy cannot react quickly with its policy instruments to unforeseen damages, either the damages will be borne by the public as a public bad or the costs of damage reduction will be left with the government. Then the costs of risk reduction are not attributed to the polluter, and social risk will not be reduced in an efficient way.[1] Of course, if irreversibilities prevail, the flexibility of the policy response is not an issue.

The problem whether the political process can react swiftly to new environmental situations relates to two different aspects. First, the total quantity of tolerable pollutants ambient in the environment may have to be reduced quickly; second, instruments specifying emissions may have to be changed. The problem arises whether some policy instruments are better in taking into account the problem of uncertainty. Some people favor standards for individual facilities in order to cope with this type of uncertainty of environmental degradation claiming that the individual polluter can be controlled much better. However, it is highly questionable that in an institutional setting with emission norms for individual agents, that is nontransferable permits, the total level of pollutants ambient in the environment can be changed more easily than in a setting of emission taxes or transferable discharge permits. Emission standards and nontransferable permits may prove to be rather rigid in reality. Price mechanisms allow a better allocation of the scarce volume of tolerable emissions if emission taxes or effluent fees can be changed in some quasi-automatic way without parliamentary action for each change (see chapter 8).

[1] Note that there is a trade-off between flexibility and the insurance premium. If environmental policy cannot react quickly to unforeseen environmental damages, a higher insurance premium is mandated, i.e., a higher environmental quality has to be established.

Also, transferable permits will signal quickly variations in environmental scarcity. Moreover, price instruments will introduce a more stimulating incentive to reduce emissions in the long run.

The Response of the Polluter Under Uncertainty

The problem of risk reduction is more complicated than just to introduce incentives to lower emissions. The problem is that the environmental impact of pollution is uncertain. And the question is how this uncertainty should be reflected in the institutional mechanism of attributing the costs of risk reduction. The problem is aggravated by the fact that the agent drawing up the institutional setting does not only lack information on the impact of the level of pollution on the environment, but he or she also does not know how the individual firm or the individual household will react to the policy instruments chosen. The policymaker is unaware of the firm's abatement and costs function, its technology etc. When devising an institutional mechanism the regulator does not know the reactions of the different agents and, given their reaction, he does not know how their response will influence his policy target. In the German economics literature this general problem of economic policy has been studied under the heading *Ordnungspolitik* (Eucken 1952), more recently it has become known as the principal-agent problem (see chapter 8).

How the individual polluter will steer this abatement processes if he faces uncertainty on the environmental policy instruments to be used becomes relevant because the individual polluter experiences costs of adjustment when environmental policy is changed. These costs relate to capital costs, because abatement capital cannot be adjusted to new policy instruments quickly. Costs also relate to the production technology and such phenomena as location as well as sectorial and regional structure. In the case of uncertainty, the individual polluter will form expectations on the policy instruments used, and these expectations will influence his abatement behavior. Moreover, the polluter as a political group will attempt to reduce uncertainty by influencing policy instruments. Environmental policy instruments should be devised to reduce adjustment costs and to prevent "overshooting".

About the Author

Horst Siebert is president-emeritus of the Kiel Institute of World Economics, Heinz Nixdorf Professor in European Integration and Economic Policy at the SAIS Bologna Center of Johns Hopkins University in Italy. He received his education at the University of Cologne, the University of Münster, and Wesleyan University, Connecticut. He was assistant professor of economics at Texas A&M University (1967–1968) and held chairs as professor of economics at the Universities of Mannheim (1969–1984), where headed the Research Unit "Staatliche Allokationspolitik im marktwirtschaftlichen System" of the German Research Association, Konstanz (1984–1989), and Kiel (1989–2003) where he headed the Kiel Institute for the World Economy. He was visiting professor at the University of Aberdeen, Australian National University, the University of California at Riverside, Harvard University, the Conservatoire National des Arts et des Métiers in Paris, the University of Grenoble, the Center for Energy Policy Research and the Sloan School of Management at the Massachusetts Institute of Technology, the National Bureau of Economic Research in Cambridge, US, the University of New Mexico in Albuquerque, New York, University Resources for the Future and the Robert Schumann Center of European University Institute in Florence. He held the "Vereniging voor Economie" visiting chair at the Rijksuniversiteit Gent in 1990/91 and has an honorary doctorate from that institution. During 1990–2003, he was a member of the German Council of Economic Advisers ("Five Wise Men") and in 2002–2004 of the "Group of Economic Analysis (GEA)" advising EU president Romano Prodi. Since 2005 he is a member of the "Group of Economic Policy Analysis (GEPA)" advising EU president José Manuel Barroso. He was a member of the EC Rask Force and "The Environment and the International Market" in 1998–1999 and of the Quota Formular Review Group of the IMF in 1999–2000. He is Honorary Member of Zheijang University in Hangzhov. He has been awarded the Ludwig-Erhard-Prize for Journalism in Economics (1999), the Karl-Bräuer-Prize of the German Taypayers Association, and the August-von Hayek Prize for Journalism in Economics (2007).

His books include among others: *Zur Theorie des regionalen Wirtschaftswachstums* (1967), *Regional Economic Growth, Theory and Policy* (1969), *Das produzierte Chaos: Ökonomie und Umwelt* (1973), *Analyse der Instrumente der Umweltpolitik* (1976), *Ökonomische Theorie der Umwelt* (1978), *The Political Economy of Environmental Protection* (with A. Berthoin Antal, 1979), *Trade and Environment: A Theoretical Inquiry* (with J. Eichberger, R. Gronych and R. Pethig, 1980), *Ökonomische Theorie natürlicher Ressourcen*

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