Regulating the International Environment: A Conceptual Model and Policy Implications for Water-Related Issues

by

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Abstract

The present scale of production and consumption is likely to generate adverse externalities (pollution). The dangers posed by pollution infringe on the welfare of countries, depending on the type of environmental problem they face. While research is under way which links environmental degradation to the onset of civil and international war, this article focuses on the non-military instruments which governments can use to improve the state of their environment.

After briefly reviewing the literature on the relationship between environmental degradation and the onset of civil and international conflict, the basic model of environmental regulation in a closed economy will be developed; these assumptions will be relaxed step-by-step by introducing transboundary pollution, international trade, and global environmental problems. Furthermore, a brief sketch is provided how to turn the static treatment into a simple dynamic perspective on defining and achieving environmental security, followed by an application of the conceptual model to water-related problems. In the penultimate Section, some suggestions for further refinement of the concept presented here are made before turning to a summary of the conclusions.

Throughout the article, the instruments at the hand of governments are derived and the central problem for international agreements are laid out. In particular, economic, technological, and ecological factors can be employed to reduce a country's ecological vulnerability. In addition, the article points to the problem of achieving environmental security which is likely to be most severe for global environmental problems as compared to transboundary or domestic environmental problems.

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States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own sources pursuant to their own policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other states beyond the limits of national jurisdiction.

Principle 21
United Nations Conference on the Human Environment
(Stockholm, 1972)

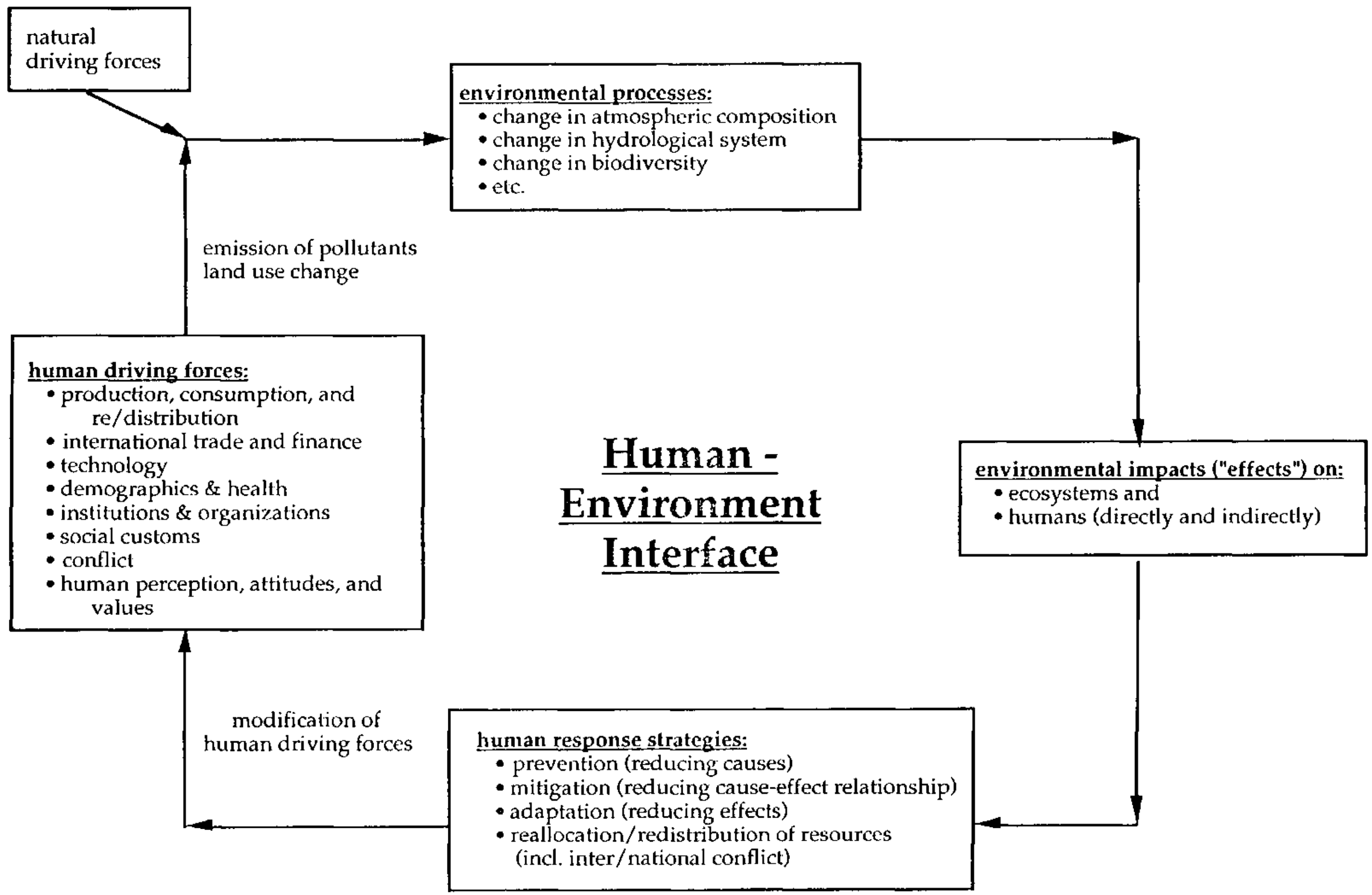
1. Introduction

The modern world is characterized by an unprecedented level of production and consumption as compared to historical levels. Regrettably, this has also led to sideeffects (negative externalities or pollution) which affect the national and global environment. While national governments may be able to cope with purely domestic environmental problems, it is less clear to what extent the present interstate system is capable to protect the environment if transboundary pollution or adverse effects on the global commons, e.g., global climate change, occur as a consequence of economic activities. As countries may disagree about the proper level of international environmental protection, the literature has raised the issue that international pollution may be linked to a nation's environmental security - with military and non-military consequences (Bächler et al. 1993; Homer-Dixon 1990; Homer-Dixon 1991; Homer-Dixon et al. 1994; Schellnhuber/Sprinz 1995). This article focuses on the *non-military* aspects of international environmental policy and (i) develops a concise concept of "environmental security," based on welfare infringements and (ii) derives the set of instruments from the concept which can be used by nationstates in an environmentally interdependent world.

This article relates to attempts to systematically describe the human-environment interface (Consortium for International Earth Science Information Network 1992) by relating the human driving forces of global environmental change (see Section 6 for a definition of global environmental change) to environmental processes, impacts on humans and ecosystems, and response strategies (see Figure 1). In order to capture the major aspects of the full cycle of Figure 1, the link among the components is modeled in terse form.

In the following section, I will briefly review earlier attempts to define environmental security as well as the literature which relates environmental degradation to the onset of civil and international conflict (Section 2). Subsequently, the basic model of environmental regulation in a closed economy (in terms of international trade and pollution) will be developed (Section 3); these assumptions will be relaxed step-by-step by introducing transboundary pollution (Section 4), international trade (Section 5), and global environmental problems (Section 6). In Section 7, a brief sketch is provided how to turn the static treatment into a simple dynamic perspective on defining and achieving environmental security. In the penultimate Section, some suggestions for further refinement of the concept presented here are made (Section 8) before summarizing the conclusions.

Figure 1: **The Human-Environment Interface**



2. A Brief Review of the Literature on Environmental Security[1]

The growing awareness of the limitations of the natural resource base as well as the adverse impacts of human activities on the environment (pollution) led several writers to conjecture about infringements on the "environmental security" of a country. For example, Görrissen defines environmental security as the "absence of and protection from extreme pollution loads and adverse influences on the environment" (translation by the author). Conversely, he defines

> ecological insecurity as a situation where environmentally damaging pollution which originates in one political system has ecological (...) effects on another political system (Görrissen 1990/91, 1990, 397, translation by the author).

As this article will show, this mainly captures the transboundary aspect of international environmental security and excludes global environmental problems as well as the impact of trade on the international pollution structure. While Görrissen avoids the link of environmental degradation to military response strategies, Bächler et al. are focusing on a new role for the military under conditions of environmental insecurity, i.e., the military may

> protect (a country) from environmental impacts of foreign origin by using military intervention to eliminate the source of damage or fight the originator, or to protect one's own resource base and environment from military attacks from abroad, or to protect a country from violent conflicts which may result from environmental degradation (Bächler et al. 1993, 75, translation by the author).

These two definitions only illustrate the varying scope of environmental security and the range of interventions which may be considered to alleviate the problem.[2]

A variety of attempts have been undertaken to provide a typology of environmentally induced conflicts. Of particular interest are the collaborative studies undertaken by Homer-Dixon and the American Academy of Arts and Sciences (Homer-Dixon 1990; Homer-Dixon 1991; Homer-Dixon 1994; Homer-Dixon et al. 1994) which combine conceptual perspectives with a series of case studies. In terms of conceptual development, this group of researchers concentrates on the effect of environmental changes on the onset of conflict. At the very heart of their hypotheses are the effects of "decreased agricultural production, economic decline, population displacement, and disruption of legitimized and authoritative institutions and social relations" (Homer-Dixon 1991, 91) on the probability of militarized conflict. Regrettably, the studies seem to lack a clear measurement concept, methodological rigor in testing its hypotheses (Homer-Dixon/Levy 1995; Levy 1995), and suffers from definitional problems (Dabelko/Dabelko 1995, 5).[3] Furthermore, many of the hypotheses are neither convincingly supported or rejected by the commissioned case studies, such as Suhrke (1993).

One of the best studies on environmental security undertaken so far is the classical book by Durham on the origins of the so-called "Soccer War" between El Salvador and Honduras in the 1970s (Durham 1979). Taking a rather broad perspective (supported by convincing empirical evidence), Durham is able to show how human driving forces (Stern et

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1 This section partially builds on Schellnhuber and Sprinz (1995, manuscript version).

2 For a broad discussion of definitions of environmental security and the history of efforts to study it, see Dabelko and Dabelko (1995) and Matthew (1995).

3 The triad decrease in quality and quantity of renewable resources, population growth, and resource access are all suggested to lead to increases in environmental scarcity - making one variable close to identical with the dependent variable (in a static analysis) see (Homer-Dixon 1994). Since environmental scarcity is itself an expression about the quality, quantity, and regularity (!) of an environmental resource (see Schellnhuber/Sprinz 1995), Homer-Dixon's concept confounds structural with definitional (or measurement) aspects.

al. 1992), population pressure, and changed economic conditions in particular, lead to migration, utilization of marginal agricultural areas, resource competition, deportation of the illegal migrants, and interstate war.

In this article, I will not attend to conflict resolution by military means. Instead, I will develop a concept which allows to link economic activities and pollution in a parsimonious manner and derive the instruments which countries may use to achieve desired levels of environmental quality. Thus, it helps answer why we actually find fewer incidences of environmentally induced violent conflict than we might expect at first (see The Economist 1996). Thus, this article will present its own perspective on defining international environmental security and how it can be achieved under a variety of conditions, ranging from purely national to transboundary and trade-related pollution problems. A subsequent section presents an extension of the concept to global environmental problems such as the greenhouse effect. In summary, this article looks at the broad range of instruments at the hand of governments to manage environmental security - which is lacking from the present literature.

3. The Basic Building Bloc: A Closed Economy With Purely Internal Pollution

In general, countries wish to maximize their welfare while remaining sovereign (i.e., free from influence from outside their country). For most political systems, a high level of economic production and consumption is desirable, whereas military threats, adverse external impacts on its economy (e.g., unwelcome movements of production factors) or environment (e.g., degradation of forests, arable land, or air quality) are eschewed. This article focuses on how economic and environmental policy instruments allow for both economic well-being and environmental protection in a world of international pollution. While it is acknowledged that militarized interstate conflict may occur in order to "resolve" unfortunate international economy-environment trade-offs, this article derives the broad array of instruments at the hand of national governments to achieve environmental goals.

In order to clearly derive the set of instruments at the hand of governments, a model world has to be developed. The approach taken below is best captured by the term "conceptual modeling." According to Huggett, this type of modeling is useful to

> express ideas about components and processes deemed to be important in a system, and some preliminary thoughts on how the components and processes are connected (Huggett 1993, 6).

In this article, I will use the abstract notion of an externality as the (positive or negative) sideeffects of otherwise legitimate economic activities - which are generally not added or subtracted from the measurement of the gross domestic product (GDP). The principal negative homogenous externality considered here is *pollution* as a result of the level of production.[4,5]

The model to follow is based on a few standard economic assumptions for a macroeconomic model:

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[4] The model can also accommodate pollution as the result of consumption of a commodity or a mixture of both production and consumption. For clarity of presentation, I restrict myself to pollution resulting from production of goods and services. Problems of exhaustible or slowly renewable natural resources are excluded from this exposition.

[5] Economic activities result in the strongest human-environment interaction as compared to the socio-cultural and political links with the environment. Therefore, I will concentrate on the economic-environment interface in this article.

(i) Only up to two economies exist, labeled "domestic" ("d") and "international" ("i").[6]

(ii) These economies produce identical a single polluting good "Y" together with other non-polluting goods,[7] although the supply (aggregated cost) curves ("S") - which relates the quantity of a good produced to its production costs - do not have to be identical across countries due to differences in factor endowments. The "S" slopes are monotonously increasing because of decreasing returns to scale and increasing scarcity of factor inputs. Furthermore, the polluting good cannot be substituted by non-polluting goods.

(iii) Each country has a demand curve ("D") for the good Y. Good Y is a normal good, i.e., consumers will demand more of it as prices decrease. In addition, increasing levels of consumption of Y lead to decreasing marginal utilities for consumers of Y. For this reason, the D curves show a monotonously downward slope.

(iv) Economies tend to be in equilibrium, both for commodities and services, financial markets, as well as for factor inputs.

(v) The level of production of Y is related to the amount of externality by the coefficient "e",[8] i.e.

$$E(Y)= e * Y \tag{3.1}$$

with

$$(d E/d Y) > 0. \tag{3.2}$$

(vi) For each economy "d" or "i," the maximum environmental assimilative capacity ("MAC") can be easily and unambiguously determined, and any production which leads E(Y) to exceed MAC generates severe environmental damage. The exceedance of MAC is assumed to be unacceptable to national governments.[9]

(vii) Governments only wish to maximize production of Y while staying within their own maximum (environmental) assimilative capacity ("MAC"), i.e., E(Y) ≤ MAC. Governments *will* intervene by using instruments at their disposal if they anticipate or experience exceedances of MAC. Environmental goals take priority over maximum economic production if exceedances of MAC are anticipated to occur. Only governments intervene into the economy to accomplish environmental goals.

(viii) The initial focus is on a one-period, static model.

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6 "International" may also be seen as the "rest of the world" from the perspective of "d."

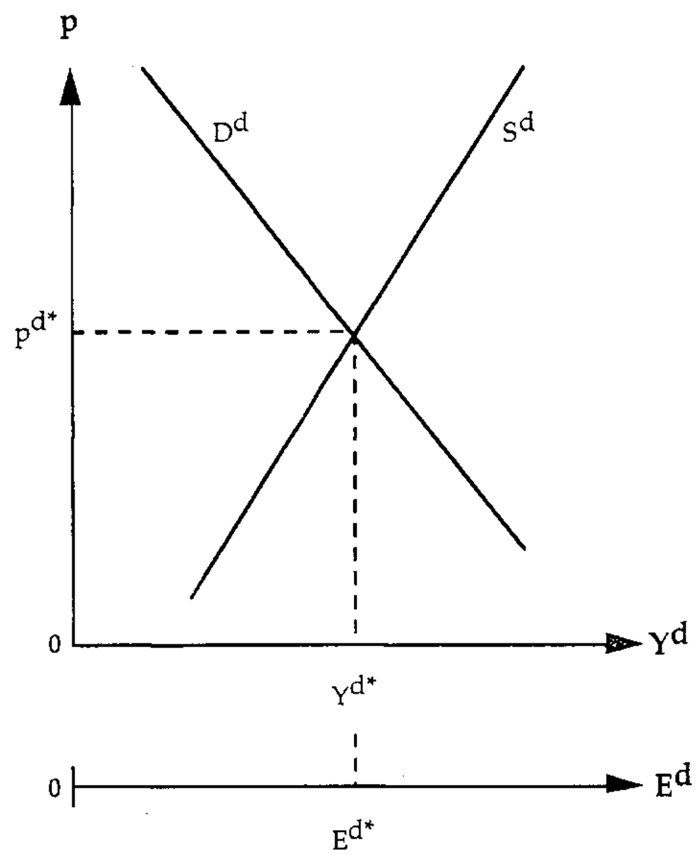
7 The non-polluting goods will not be considered further in this article, because, by definition, they do not have any environmental consequences.

8 The term "e" can be interpreted as the marginal externality or pollution coefficient per unit of Y. For reasons of exposition, I have chosen a positive linear relationship (see equation (3.1)), however, e can be chosen as increasing exponentially with the level of Y (e.g., $E = \exp(Y)$, i.e., $(d^2 E/d^2 Y) > 0)$) or with asymptotically declining increases as a function of Y (e.g., $E = e * \ln(Y)$, i.e. $(d^2 E/d^2 Y) < 0)$). The general results will not change with the functional form of the relationship.

9 This assumption is similar to the use of threshold values in epidemiology. Exceedances of MAC can be interpreted as damage functions which are zero for E(Y) ≤ MAC and approach positive infinity for E(Y) > MAC. Empirically deriving values for MAC may be difficult; Section 8 will provide a more refined notion of MAC.

Assumptions (i) through (v) are summarized in the following graphical exposition of economy d (Figure 2).[10]

Figure 2: **The Basic Model of Coupling Economic Activity and the Level of Externalities**



Without international trade in the polluting good,[11] country d will achieve the static equilibrium (Y^{d*}, p^{d*}, E^{d*}), i.e., it will produce the equilibrium amount Y^{d*} at price p^{d*}. As a result, the amount E^{d*} of the uniform externality is produced.

In principle, economic activities do not have to lead to unacceptable levels of pollution, i.e., as long as $E^{d*} \leq MAC^d$ for a given period (e.g., $MAC^d = E^{d'}$ in Figure 3). However, if $MAC^d \leq E^{d*}$(e.g., $MAC^d = E^{d''}$) , then a government faces a trade-off between environmental and economic goals and, given assumption (vii), will intervene (see below for the set of instruments).

Since environmental security refers to the protection of welfare derived from environmental quality, environmental security for a country with purely domestic environmental problems can be defined as

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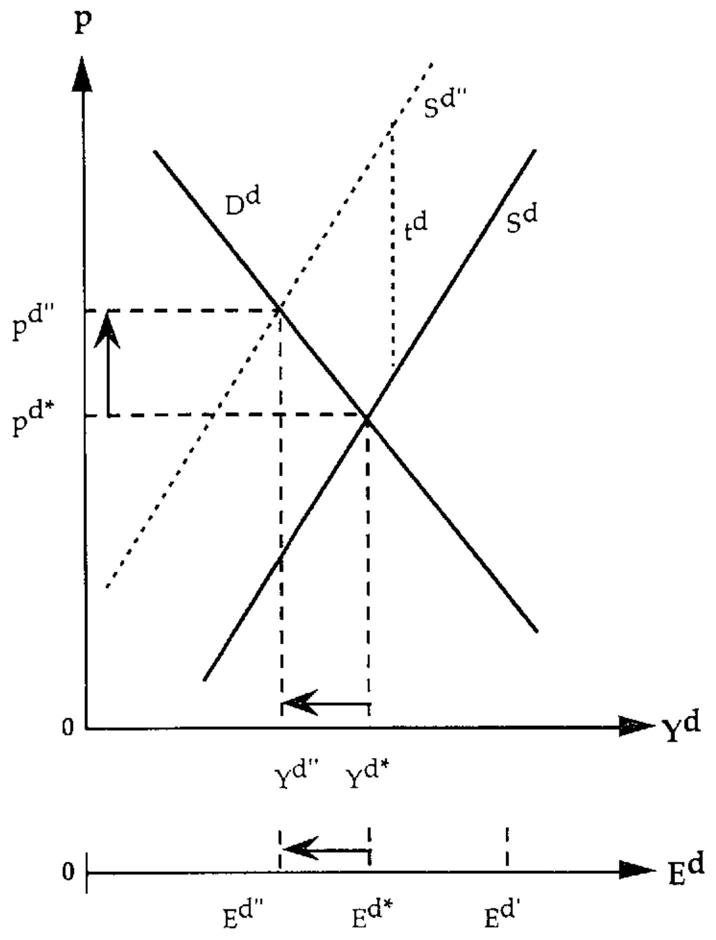
10 Economy i is modeled analogously, however the slopes of the supply and demand curves as well as the pollution coefficient e can vary substantially across economies.

11 The treatment of only one country, such as d, resembles the treatment of the global economy at large.

$$E^d \leq MAC^d \ . \tag{3.3}$$

<u>Figure 3:</u> **Government Intervention in a Closed Economy (*without* transboundary pollution)**



Discussions of international environmental security and the urgency to use interventions into the economy for environmental reasons assume that the environmental assimilative capacity of the environment is already exceeded or will be exceeded in the near future. Given the assumptions of the model, governments will have to intervene into the economy if $MAC^d = E^{d''}$ represents the environmental threshold. Excluding changes in the slope of the demand function (steeper negative slope resulting from environmentally less demanding lifestyles[12]) or supply function (increasing the slope as a result of valuing natural resource inputs more dearly), a government is left with the following policy instruments:

[12] The steeper demand curve results in less environmental damage per unit of Y, however, because of the decreased price elasticity of demand as compared to the D curve depicted in Figure 3, interventions will have to be more pronounced to achieve the same absolute reduction in E^d.

(I 1) Imposition of the Pigouvian tax "$t^{d''}$" per unit of Y (sift of S^d to $S^{d''}$) such that the intersection of $S^{d''}$ with D^d will result in $E^{d''}$ = $MAC^{d'}$ (see Figure 3).[13] As an alternative, consumption could be taxed by the amount t^d per unit of Y consumed. In both cases, the equilibrium quantity produced and consumed will shrink, and the equilibrium price $p^{d'}$ will rise to $p^{d''}$.

(I 2) Reduction of the quantity of production such that $E^{d''}$ = MAC^d. This could be accomplished by allocating production or pollution quotas to producers of Y.[14]

(I 3) Reducing e^d by supporting or mandating "ecologically" benign production methods, e.g., CFC-free coolants. This should lead to an increasing slope of the supply function or a similar effect as the Pigouvian tax in terms of compliance with (3.3).

(I 4) Enlarging the MAC of an economy, e.g., by partial recycling of E into the production process (as an input), reducing the toxicity of E, etc. As in the previous case, this should affect the supply function by shifting it up to the left or increasing its slope.

Even with this simple model it can be shown that a governments may easily be faced with a threat to its environmental quality, however, with some anticipation (in the one-period model) it has an array of four instruments at hand which can be incorporated in an policy mix.

4. Transboundary Pollution

In the following, the single country restriction will be relaxed in the sense that countries may pollute each other by way of a common environmental medium, e.g., air pollution, river pollution, or radioactivity. These cases will be subsumed under the category of "transboundary" pollution. In effect, this allows countries to infringe on the sovereignty of each other by reducing welfare abroad. For reasons of exposition, I will restrict myself to a two-country case consisting of d and i (or the rest of the world from the standpoint of country d). The other assumptions of the prior section are maintained. In particular, country i produces emissions by way of

$$E^i = e^i * Y^i \quad . \tag{4.1}$$

Furthermore, it is assumed that countries export a share "f" (transboundary flux) of their emissions E abroad , namely $f^{i->d}$ or $f^{d->i}$.[15] Applying a balance sheet approach to transboundary pollution, the environment in country d has to cope with the following sum of pollution within its boundaries:

E^d = total domestic release of E - (exports of domestic pollution to i)
+ (import of pollution from i)

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[13] It is assumed that the newly generated government income will be used to repay historical debts and has no effect on the slopes of the aggregate supply or demand functions.

[14] Using production quotas will lead to potential redistribution of rents between producers and consumers - depending on the price level after the allocation of quotas. Production quotas can be allocated by way of non-market mechanisms which are the object of research in public finance (Grass/Stützel 1983).

[15] The direction of the arrow (e.g., i->d) describes the actual flow of the transboundary pollutant.

or, more formally,

$$E^d = (e^d * Y^d) - (f^{d->i} * e^d * Y^d) + (f^{i->d} * e^i * Y^i),$$
$$= (1 - f^{d->i}) (e^d * Y^d) + f^{i->d} * (e^i * Y^i) \quad (4.2)$$

with $0 \leq f^{d->i} \leq 1$ and $0 \leq f^{i->d} \leq 1$.

Equation (4.2) shows the extent of interdependence among countries, the degree of which is dependent on the level of production in each country, the pollution intensity of production, and the particular degrees of exchange of pollution across borders. Country d may be partially able to impose pollution onto its neighboring country, thus improving its possibilities to expand production within the MAC of its environment, however, it is also liable to reductions on its freedom to use all of its own environmental assimilative capacity because of involuntary pollution imports. If we assume for illustrative purposes that $f^{d->i} = 0$ (i.e., no pollution exports from d to i), then Figure 4 displays the adverse impact which country d faces due to the amount of imported emissions $E^{i->d}$: If country d was previously producing at the level $E^{d*} = MAC^d$, then it will have to reduce its production in the amount of $Y^{d*} - Y^{d'}$ or ask country i to reduce its emission exports (see also (I 5) through (I 8) below) in order to pursue its environmental goal. In the absence of reduction of pollution exports from i, this can be accomplished by introducing a domestic producer tax in the amount t^d (which leads to a shift of S^d to $S^{d'}$ (see Figure 4) or the use of any of the the other instruments mentioned in the previous section.

Equation (4.2) provides a concise perspective of the meaning of "environmental interdependence." If a country reacts to pollution imports with purely domestic adjustment ("victim or pollutee pays principle"), it will have to also absorb a welfare loss in terms of producer and consumer welfare foregone in the amount characterized by the triangle abc (see Figure 4). In the case of transboundary pollution, environmental security for individual countries may be defined as the ability for each country to stay within its MAC despite pollution imports. International environmental security is achieved if *all* countries (d and i) fulfill their individual environmental security conditions.

Besides the four intervention instruments considered in the previous section, country d may try to use the following four additional instruments

- (I 5) ask i to introduce the optimal Pigouvian production tax;[16]
- (I 6) demand i to reduce the level of production Y^i;
- (I 7) support more benign production methods in i by influencing e^i ("technical cooperation"); and
- (I 8) ask country i to relocate its polluting activity so as to lessen the transboundary pollution coefficient $f^{i->d}$.

All these four instruments should be compatible with the "polluter pays principle" (PPP) of OECD and while enhancing the environmental security of d, they also enhance the environmental security of i (with the exception of (I 8)). These instruments will normally require some sort of economic or technological transfer from d to i, however, given the assured deadweight loss to d in the absence of any interventions by i, d has an interest to partially subsidize pollution reducing activities in i.[17] To the degree that i pursues its own environmental goals such that $E^i \leq MAC^i$, additional increments of pollution reduction in i may have to be fully compensated by d. The logic underlying this conclusion is that each country may just undertake restrictions of its pollutant activity such that it does not exceed its own MAC - despite pollution imports. From the perspective of the Pareto criterion, this

[16] Optimality refers here to a reduction of pollution imports from i to d such that d does not violate its MAC^d. Introducing the optimal Pigouvian tax from i's perspective may not necessarily be sufficient from d's perspective.

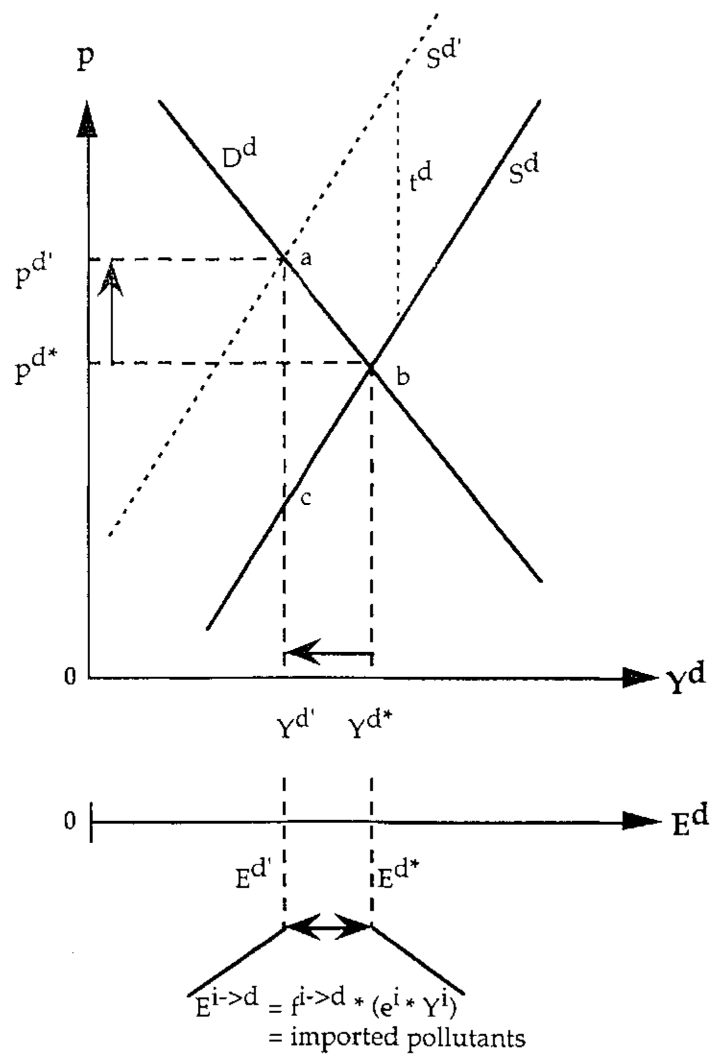
[17] This does not hold if domestic adjustments, such as measures to increase one's own MAC, are more efficient than international transfers.

leads to improvements for both countries - but may be insufficient to achieve environmental security in *all* countries.

The crucial strategic element is that if one country radically reduces its own emissions in order to achieve its environmental goal, it is likely to reduce its impact on other countries by way of reduced pollution exports. In turn, foreign countries have less of an incentive to reduce their emissions, esp. if they already arrive at their own MAC with the help of reduced emission imports. Therefore, theories of international bargaining may be extremely helpful in modeling the degree of abatement efforts undertaken internationally in the presence of transboundary pollution.

In an interdependent world, countries can resort to self-help by influencing economic performance, enlarging the assimilative capacity of the environment, or modifying pollution exchange coefficients. While these strategies may be extremely costly if one relies on the "victim pays principle" only, they also show that under a limited set of assumptions countries can resort to a wide range of non-military instruments to improve the condition of their environment.

Figure 4: Government Intervention: The Case of Transboundary Pollution



5. International Trade and Transboundary Pollution

While countries may influence the environmental security of their neighbors by way of transboundary pollution, an additional way of determining the international pollution structure is afforded by international trade in goods and services. As countries may have different shapes of their supply and demand functions due to differences in natural endowments, valuation of goods by consumers, and differences in the scarcity of factor inputs, international trade opens up the possibility of increased welfare in all countries involved.[18]

For the purposes of this section, the prior assumptions are maintained, especially the assumption of the production of one homogenous good in two countries. Both countries are assumed to be "large" countries, i.e., changes in the supply or demand function of each country will result in changes in the amount and structure of trade as well as the world market price for goods and services ("p^{w*}") (see Figure 5). For presentational reasons, transboundary pollution will be introduced only later in this section.

In the following, some standard results of international trade theory are shown, in conjunction with their environmental consequences. First, in the absence of international trade, countries d and i are in static equilibrium at (Y^{d*}, p^{d*}, E^{d*}) and (Y^{i*}, p^{i*}, E^{i*}) respectively (see Figure 5). Due to differences in equilibrium prices, countries can profit from international trade in the polluting good Y. If there are no restrictions on trade,[19] opening these countries to international trade will result in the world (equilibrium) market price p^{w*}, and country d will become a net exporter of good Y in the amount of

$$X^{d\text{->}i} = Y^{dw} - Y^{dw'} \qquad (5.1)$$

and i will import the amount

$$M^{i\text{->}d} = Y^{iw'} - Y^{iw} \qquad (5.2)$$

with

$$|X^{d\text{->}i}| = |M^{i\text{->}d}|,$$

i.e., the sum of exports must equal the sum of imports.

Second, this international rearrangement of the production (and consumption) patterns also leads to a new pattern of pollution as compared to the absence of international trade (closed economies), namely an *increase* of pollution emissions in d

$$\Delta E^{d} = E^{dw} - E^{d*} \qquad (5.3)$$

and a *reduction* of pollution emissions in i in the amount of

$$\Delta E^{i} = E^{i*} - E^{iw} \ . \qquad (5.4)$$

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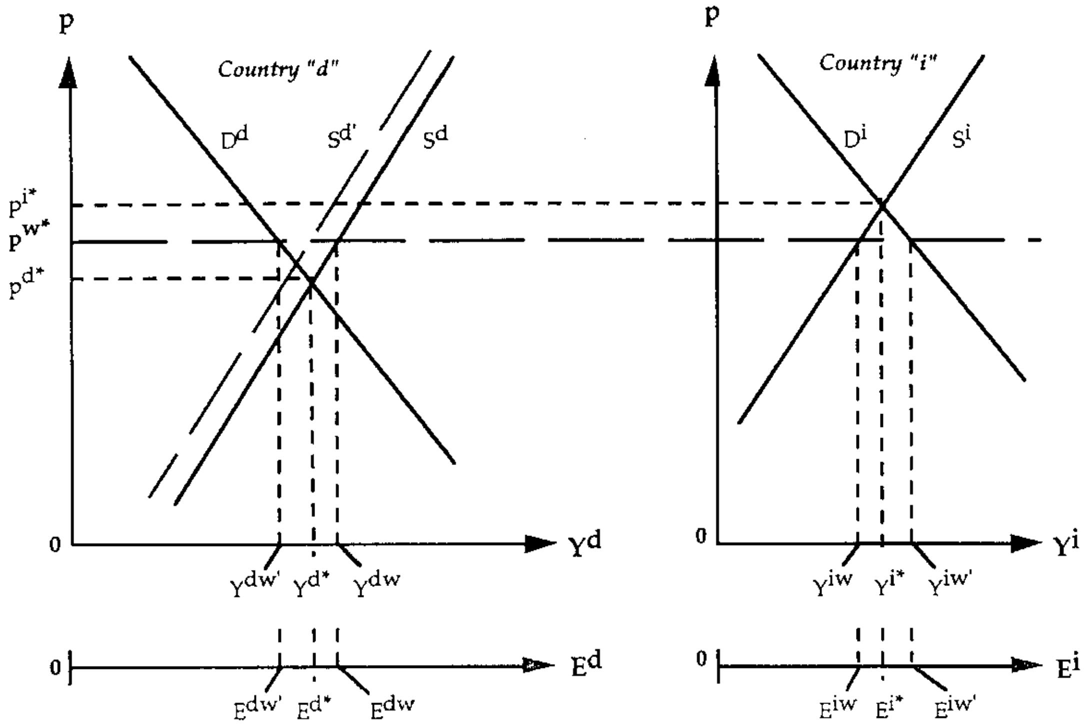
[18] If countries show identical supply and demand curves, there will be no international trade. While this is theoretically possible, it is unlikely to be the case in reality.

[19] The standard assumption is made that transport and information costs are set at zero in accordance with the "law of one price" for a homogenous commodity.

Figure 5: The International Pollution Structure in the Presence of International Trade



In conclusion, the changes in the international production structure also lead to a new international structure of pollution which may exasperate environmental problems for exporting countries and relieve the environmental situation in importing countries.[20]

In the case of international trade without transboundary pollution, the definition for environmental security is the same as in the case of transboundary pollution - with the qualification that it is the trade structure rather than transboundary pollution which infringes on the MAC of the two countries.

If country d has an environmental constraint such that $E^{d*} = MAC^d$, then d may wish to introduce a domestic pollution tax in the amount of $p^{w*} - p^{d*}$ on its production, thereby shifting S^d to $S^{d'}$ (see Figure 5). This shift of the supply curve will allow country d to achieve its MAC if p^{w*} would prevail. However, at p^{w*} (incl. tax), the imports of i would exceed the exports from d (please compare $|Y^{d*} - Y^{dw'}|$ with $|Y^{iw'} - Y^{iw}|$), and the world market price will have to rise. This rise in the world market price will lead to a production level exceeding Y^{d*} and an exceedance of the MAC in d. As a consequence of the international price mechanism, the optimal Pigouvian tax has to be higher than in the case of purely domestic pollution.

More generally, besides the array of instruments (I 1) through (I 4), country d may also introduce - as a second best strategy - an

(I 9) export tax on Y or, if d were an importing country, an import tax.

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[20] This is the case for production externalities only. In the case of consumption externalities, the opposite pattern holds. The case of combining international trade with the case of transboundary pollution will be presented towards the end of this section.

This conceptual model has shown that in the absence of transboundary pollution, the importing country will always gain from trade if pollution is generated by way of economic production. However, this result may change if we permit the introduction of transboundary pollution. From the environmental perspective of country i, international trade is profitable as long as

pollution exports from d to i due to *increased* production in d
< pollution reduction effective in i due to *reduced* production in i, or

$$| f^{d->i} * [e^d (Y^{dw} - Y^{d*})] | < | (1 - f^{i->d}) * [e^i * (Y^{i*} - Y^{iw})] |$$

which is equivalent to

$$| f^{d->i} * [e^d * (Y^{dw} - Y^{d*})] | < | f^{i->i} * [e^i * (Y^{i*} - Y^{iw})] |, \quad (5.5)$$

and for country d (without environmental taxes) it holds that

increase in pollution in d (due to production increases) which remain in d
< reduced import of pollutants from i due to production decreases in i

$$| f^{d->d} * [e^d * (Y^{dw} - Y^{d*})] | < | f^{i->d} * [e^i * (Y^{i*} - Y^{iw})] | \ . \quad (5.6)$$

It is normally assumed that (voluntary) international trade in goods and services is beneficial to all those countries engaging in it. This certainly remains true for the welfare gains enjoyed from the specialization of international production, however, from an environmental perspective, international trade will be beneficial for both countries from an environmental perspective in the presence of transboundary pollution only if both inequalities (5.5) and (5.6) hold. If country d introduces the optimal pollution tax on its supply curve such that $E^{d*} = MAC^d$ is not exceeded, then

- international trade in goods and service will still occur,
- on a lower level as compared to before imposition of environmental taxes,
- at higher world market prices for the good traded as compared to the case without an environmental tax, and to
- the environmental benefit of both countries.[21]

For the case of international trade among large countries in the presence of transboundary pollution, improvements in the degree of environmental security for a country is defined by equations (5.5) or (5.6) respectively, and international environmental security is achieved if both countries stay within their respective MACs.

Under favorable circumstances, international trade in the presence of transboundary pollution may permit the accomplishment of environmental security in both countries as compared to the situation without trade, i.e., if a country in the pre-trade situation does not exceed its environmental assimilative capacity while the other does so and international trade leads to a production structure where both countries are complying with their MACs. However, the strategic problem remains to what extent countries need to compensate other countries if they wish to induce pollutant reductions abroad beyond those undertaken in each country for reasons of pure self-interest.

Until now, it has been assumed that countries are "large" economies, i.e., they are able to influence the world market prices by way of shifts in their supply and demand functions and in terms of sheer size (such as the US economy). This does not hold for the

[21] Strictly speaking, country d emits the same pollution as in the case of a closed economy, but country i definitely decreases its pollution level. This outcome still complies with the Pareto criterion. This is equivalent to permitting "≤" instead of "<" in equations (5.5) and (5.6).

group of so-called "small" economies which are defined as price takers in international commodity markets. When trading with large countries, they can only adjust their production level Y and the amount of exports according to prevailing world market prices. This idea is graphically captured - in the absence of transboundary pollution - in Figure 6. In comparison to the previous case of "large" economies, the repercussions in terms of production and trade are more *strongly* felt - as is the impact on the environment.

In case the potentially exporting, small economy remains a closed economy, its static equilibrium solution is $(p^{d'}, Y^{d'}, E^{d'})$. If $E^{d''} = MAC^d$, then domestically determined production does not cause any environmental problems. However, as international prices for the good are determined outside the country and reach, for example, the level p^{w^*}, country d will be in equilibrium at $(p^{w^*}, Y^{d^*}, E^{d^*})$. Both production levels and pollution levels increase dramatically as compared to the equilibrium solution for a closed economy. If $E^{d''} = MAC^d$, then given our assumptions about government behavior, the government in country d needs to intervene, e.g., by imposing a tax in the amount of

$$t = p^{w^*} - p^{d''}$$

which leads to a shift of the supply curve from S^d to $S^{d''}$. In comparison to the case of the large economy, introducing the environmental tax domestically will have no repercussions on international markets and barely or zero effect on the amount of commodity Y traded worldwide. However, imposing a tax in d will be strongly felt, because it has to fully pay for the costs of environmental protection without changing the international price structure. This clear structure of losses to their economies in the amount of

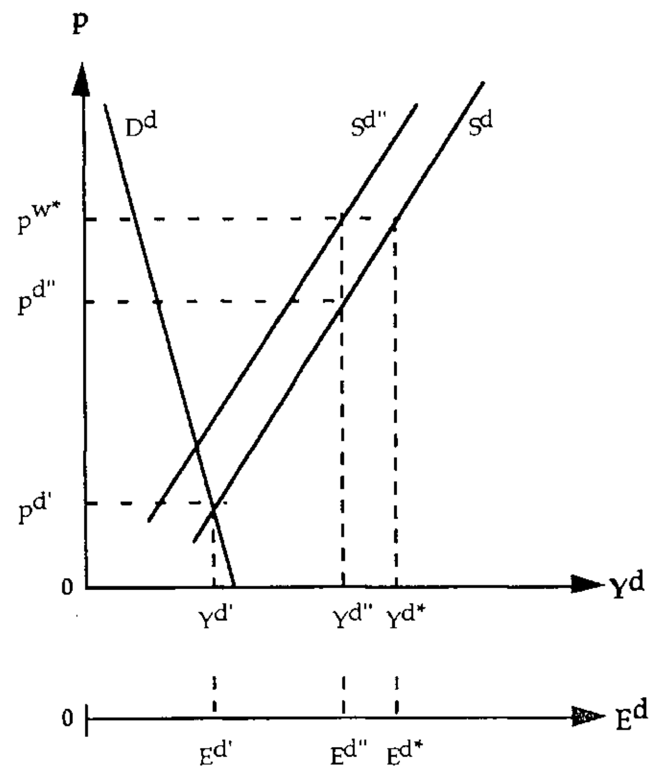
$$(Y^{d^*} - Y^{d''}) * p^{w^*}$$

is unlikely to make relatively poor small economies enthusiastic about imposing environmental taxes domestically as compared to large economies, because the latter can change the world market prices by way of unilateral environmental policies.

Small economies need *not* be minor polluters in the international context. If we permit transboundary pollution, even small countries may hurt their neighbors to a quite measurable degree. For example, let us assume that the foreign (large and small) economies use production technologies with account for a very small e^i or even $e^i = 0$ and do by far not approach the upper limit of their respective MACs. If $0 < e^d \leq 1$ and $0 < f^{d \to i} \leq 1$, then even small production levels in d can impede measurably on the environmental well-being of other countries - at least in the short run. Examples of such conditions include the hazardous production of electricity with substantial releases of radioactivity (e.g., feared by some Central and Western European countries to be the case for Eastern Central Europe and the successor states of the former Soviet Union) (i.e., spread by way of transboundary pollution) or the spread of viruses by way of trade (e.g., potential spread of so-called "mad cow disease" by selling British beef on the European continent) (spread by way of international trade).[22]

[22] This particularly applies to (living) livestock. In a multi-period model, such virus transmission and spread would be subject to a declining rate of growth, however short-term damage at home and abroad may be quite substantial. The impact of pest incidences during the Middle Ages in Europe serve as a pertinent reminder.

Figure 6: **Pollution and International Trade: The Case of the "Small" Economy**



6. Global Environmental Change

Global Environmental Change (GEC) can be seen as resulting from "widespread regional events" and "globally linked events." Whereas the former category only relates to similarities among a large group of events which are not spatially related to a substantial degree, the second category affords a summation of emissions from a diverse group of emitters, a global link medium (such as the atmosphere), and (varying or constant) effects around the globe. In essence, this is a modification of the case of transboundary pollution with a separation of cause and effect externalities.

The basic assumptions of Section 2 are maintained, however, the pollution externality needs a more refined treatment. First, pollution emissions are generated by both countries and the effect results from the *transformed combined* emissions. We will label the emissions which lead to global environmental processes the "cause" externalities ("E^{cause}"), such as CO_2 or CFC releases. The effects of these emissions themselves may be non-existent or relatively benign, however, once they are added ("$GEC^{untransformed}$") and transformed ("$GEC^{transformed}$", e.g., change in the reflectivity of the earth's atmosphere or unequal thinning of the stratospheric ozone layer), effects may be felt. Leaving the modeling of the mostly chemical transformations to natural scientists, we will focus on the effects of these transformed emissions on economies. This "effects" externality (E^{effect}) is of importance, since it is the anticipation of the effects which makes prevention strategies[23] so attractive - although potentially costly. It should be noted that the effect of global

[23] For the purposes of this article, "prevention" is defined as reducing causes, "adaptation" as reducing effect, and "mitigation" as reducing the cause-effect (or transformation) relationship.

environmental change may vary across countries because of differences in their exposure (e.g., different storm patterns by region as a result of regional temperature change or the unequal thinning of the stratospheric ozone layer) and differences in the maximum environmental assimilative capacity (MAC^{effect}) (e.g., resilience of crop varieties to moisture changes). We will denote the effect of GEC on a particular country with the coefficient "g" (global) and the "direction" of its effects by superscripts.

More formally, the relevant relationships under the conditions of global environmental change can be summarized as follows:

$$GEC^{untransformed} = \sum_{i,d} E^{cause}, \quad (6.1)$$
$$GEC^{transformed} = f\,(GEC^{untransformed}), \quad (6.2)$$

with

$$(d\,GEC^{transformed} / d\,GEC^{untransformed}) > 0 \;. \quad (6.3)$$

To simplify the presentation, we leave out the transformation component for the effects side of GEC:

$$E^{d\ effect} = g^{GEC\text{->}d} * \sum_{i,d} E^{cause}, \text{ i.e.,}$$
$$E^{d\ effect} = g^{GEC\text{->}d} * (e^d * Y^d + e^i * Y^i), \quad (6.4)$$
$$E^{i\ effect} = g^{GEC\text{->}i} * (e^d * Y^d + e^i * Y^i), \quad (6.5)$$

with

$$(d\,E^{d\ effect} / d \sum_{i,d} E^{cause}) > 0,\ (d\,E^{i\ effect} / d \sum_{i,d} E^{cause}) > 0 \quad (6.6)$$

and

$$g^{GEC\text{->}d} \geq 0,\ g^{GEC\text{->}i} \geq 0. \quad (6.7)$$

with "i" and "d" symbolizing countries and "$g^{GEC\text{->}d}$" and "$g^{GEC\text{->}i}$" the coefficients of the effects which the transformed global environmental externality has on countries d and i respectively.

Given the assumptions made in Section 2, we can infer that governments strive to keep the externality effects within the bounds of their maximum environmental assimilative capacity for effects (MAC^{effect}):

$$E^{d\ effect} \leq MAC^{d\ effect} \text{ and} \quad (6.8)$$
$$E^{i\ effect} \leq MAC^{i\ effect}. \quad (6.9)$$

In terms of defining environmental security under conditions of GEC, individual country environmental security is represented by equations (6.8) and (6.9) respectively; for global environmental security, both equations have to hold *simultaneously*.

The array of instruments at the hand of governments which have not yet been mentioned previously is enlarged by

(I 10) modifying the country-specific effects coefficient of GEC, namely $g^{GEC\text{->}d}$ and $g^{GEC\text{->}i}$.

This last instrument is a mitigation strategy as defined above and could consist of releasing sulfur particles for the case of the greenhouse effect or the substitution of CFCs by *less* harmful substitutes. Options of geoengineering also fall into this category.

Compared to the case of transboundary pollution, there is likely to be an even stronger strategic element involved in the decision which country shall undertake emission reductions. If countries are entirely determined to achieve environmental security by themselves, they are likely to spend huge amounts of resources to do so. Given the summation effect across all countries, they may not be able to achieve their domestic MAC (e.g., low-lying Pacific islands in the case of sealevel rise) even less likely as compared to the case of transboundary pollution problems.[24] As long as there is a major emitter of cause externalities to provide the global public good of very substantial emission reductions, others will benefit tremendously - without having incentives to contribute in turn. Global environmental problems involve truly all countries on earth (although by varying degrees), whereas transboundary pollution problems affect only a region of the earth. As the number of countries increases, the element of free-riding on emission reductions in likely increase. Thus, the strategic problem of determining which country shoulders the burden of emission reductions (e.g., carbon dioxides, chlorofluorocarbons, etc.) is the standard international public good problem which has been treated elsewhere in detail (Helm 1995; Mueller 1989; Olson 1971; Sprinz 1992, ch. 3). Theories of bargaining and game-theoretical treatment of such problems may show the greatest utility in explaining the level of actual provision of international public goods.

The problem of deciding of which country pays for emission reductions is partially reduced by the possibility of "joint implementation," a modern variant of the comparative advantage argument found in international trade theory (and elsewhere in economics). According to Pearce, joint implementation

> involves a bilateral deal, or even a multilateral one, in which countries with high costs of pollution abatement ... invest in abatement ... in a country with lower costs, and receive credit for the resulting reduction in emissions ... (Pearce 1995, 177).

Assuming that countries can agree on the degree of world-wide emission reductions as well as country-specific obligations, joint implementation allows for the cost-minimizing way to do so. However, this also involves two strategic elements. First, the original allocation of "pollution rights" may be controversial; second, the degree of credit for the high abatement cost country for activities in the low abatement cost country may have to be determined. Theories of bargaining may be useful in better understanding how these particular strategic problems are solved.

7. Some Preliminary Thoughts About Multi-Period Models

In the previous sections, environmental security was defined as complying with a sharp boundary set by the country-specific maximum environmental assimilative capacity (MAC) which should not be exceeded in *any* period. However, environmental processes and economic activities occur on an continuous time scale, and government interventions may take time - while pollutants are still released. The central question remains the degree of resilience of the environment, or - expressed differently - the possibility of medium-term overshoot of the MAC without irreversibly destroying the positively valued environment.

For reasons of presentation, I assume that the previously introduced MAC now represents the *average* value not to be exceeded over the long run (approaching infinity) and no intermediate term maxima are introduced. In each period, assimilation of the externality by the ecosystem occurs at a rate of b of all externalities present.[25] As a consequence, (1-b) times the externality present in the beginning of the period will be available at the end of the period. Then it follows that in the *end* of period 1 (and dropping country subscripts), the following equation holds for the remaining externality ("RE"):

[24] This seems to hold empirically for global climate change but less so for the international regulation of CFC emissions. See Sprinz and Vaahtoranta (1994) for an explanation of international CFC regulations.

[25] For simplification purposes, each time period is treated in discrete form.

$$RE_1 = E_1 - b * E_1 = (1-b)E_1 \tag{7.1}$$

with

$$RE_1 \leq MAC$$

and, more generally, for all n > 0

$$RE_n = (1-b)\ (RE_{n-1} + E_n) = \sum_{t=1}^{n} (1-b)^{n-t+1} E_t\ , \tag{7.2}$$

with

$$RE_n \leq MAC\ ;\ t = 1,\ 2,\ ...,\ n\ . \tag{7.3}$$

In order to more clearly show the relationship among the various components, the emissions in E_t are reexpressed in terms of rates of growth over time relative to E_1.[26] Since emissions grow at the same rate as the product Y, namely $\dot{y}$, it holds that

$$Y_2 = \left(1 + \dot{y}\right) Y_1,$$

$$E_1 = e * Y_1,$$

$$E_2 = e * Y_2,$$

and, therefore,

$$E_2 = \left(1 + \dot{y}\right) E_1 \tag{7.4}$$

For any period, equation (7.4) can be rewritten as

$$E_n = \left(1 + \dot{y}\right) E_{n-1} = \left(1 + \dot{y}\right)^{n-1} E_1\ . \tag{7.5}$$

Substituting (7.5) into (7.2) leads to

$$RE_n = E_1 \sum_{t=1}^{n} \left(\left(1 - b\right)^{n-t+1} \left(1 + \dot{y}\right)^{t-1} \right)\ . \tag{7.6}$$

From equation (7.6) it becomes obvious that the major components of the remaining externality are a function of the initial level of pollution, the degree of assimilation for each period, and the growth rate of the production of Y (which is identical to the rate of emission growth). Policy interventions into this growth process, subject to the environmental security constraint for the achievement of the goal represented in (7.3), will have to include (in addition to the instruments suggested in previous sections)

(I 11) increasing the coefficient b and

(I 12) reducing $\dot{y}$, the growth rate of Y.[27]

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[26] This assumes a linear relationship between Y and E over time. See equation (3.1) for the static case.

In addition to the derivation of policy interventions, this section also points to approaches for the conceptualization and measurement of intergenerational equity. As equation (7.3) provides an intertemporal constraint, and "overshooting" is likely to characterize the earlier periods, subsequent periods will have to fall short of the intertemporal externality average. Thus, early deviations from this average are a simple measure of how much less (or more) freedom future generations will have in choosing economic activities with negative externalities.

8. Application of the Concept to Water-Related Problems

Water can serve in two major capacities, namely as an in input (water withdrawal) as well as an output (effluent). Consequently, both the economics of renewable and non-renewable resources apply for the input function as well as the environmental economics to the output function (Tietenberg 1992). Furthermore, any environmental resource can be characterized by its quality, quantity, and extreme events (amplitude) (Schellnhuber/Sprinz 1995). In the following, I will consider the transboundary and global environmental change (open access commons) problems, each for (i) quality and quantity aspects related to water as well as (ii) water as input and output. Extreme events (such as seasonality of water supply or discharge), the distribution of property rights to water, and international trade aspects will be omitted. As shown in Table 1, the general set of instruments developed in the previous section apply to the regulation of water-related problems and permit governments to insure that water quality and quantity can be influenced - subject to the strategic considerations mentioned in the previous sections and the following section.

9. Suggestions for Future Research

The concept of environmental security presented in this article assumes a rather simple world so as to arrive at a set of instruments which reduce the human impact on the environment.

A variety or research questions can be derived from the present concept. In particular, they involve the role of knowledge concerning the MAC threshold, alternative perspectives on environmental thresholds, as well as technology and product substitution.

First, knowledge of the environmental thresholds (MAC) may change over time. As research improves, environmental problems may be judged to be more or less benign than originally thought of. Thus, governments may intervene less or more decisively to regulate a particular pollutant. Instead, we could think of two environmental thresholds, one representing reversible environmental changes (e.g., fertile agricultural land turns into land suitable for grazing only) and a non-reversible threshold (e.g., grazing land turns into desert). In general, it is expected that as governments approach the non-reversible threshold, their abatement efforts will be more ambitious as compared to a situation when they approach the reversible threshold. However, governments need not know which of the two thresholds they are currently approaching. Under conditions of incomplete information, governments have to determine their abatement efforts based on their beliefs about the type of threshold they are facing.

Second, rather than setting environmental thresholds scientifically, these could be set politically - reflecting the international differences for environmental protection. This will obviously complicate the bargaining problem to determine which country will have to reduce emissions beyond those undertaken for self-interested ends.

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[27] All the other policy interventions listed in the earlier sections remain valid, including reduction of the coefficient e by way of switching to environmentally more benign production methods. In a discrete dynamic process, it seems problematic to try to change E_1 as it may be historically given and retroactive intervention is impossible.

Table 1: **Instruments to Regulate International Water Problems**

	input (withdrawal)		output (effluent)	
instruments	quantity	quality	quantity	quality
taxation or subsidies (I 1, I 5)	yes (taxation)	yes (subsidies)	yes (taxation)	yes (taxation)
quantity regulation (I 2, I 6)	yes	*does not apply*	yes	*does not apply*
technological progress (I 3, I 7)	yes (technology for water extraction)	yes (technology for enhancing water quality)	yes (if modifying the physical state of water: gaseous instead of liquid)	yes (technology for enhancing water quality)
modifying MAC (I 4)	*does not apply*	yes (if interpreted as water quality threshold; chemical modification)	*does not apply*	yes (if interpreted as water quality threshold; chemical modification)
relocation (I 8)	yes (includes water import)	yes (includes water import)	yes (includes water "export")	yes (includes water "export")
modifying country-specific effect (open access commons only; I 10)	yes (only by changing the global balance of saltwater and freshwater)	yes (use of bacteria)	yes (shielding)	yes (shielding)
modifying coefficient of assimilation (I 11)	*does not apply*	yes	*does not apply*	yes
modifying growth rate of social product (I 12) -	yes	yes (if quantity withdrawn ultimately impinges on quality)	yes	?

Note: All entries apply to transboundary as well as open access commons if not indicated otherwise.

Third, changes in technology may dramatically alter government policy (see instruments 3 and 7). By reducing the pollution coefficient as a results of technological innovation, achieving ambitious environmental goals may become more affordable. In the extreme, polluting activities may be replaced by non-polluting ones (e.g., switch to CFC-free pollutants) and the regulation of the original pollutant becomes less important. In order to allow for a more continuos process in reducing pollution, we could introduce a second good into the conceptual model so as to focus on the substitution effects between goods of different polluting intensity. In such a two-commodity case, substitution between the production of the two types of goods could more realistically capture the ecological modernization of economies. This would also open new avenues of research in terms of better modeling the implications of the structure of international trade on the level of pollution as well as differential international specialization in the production of goods. For example, we should expect countries with higher MAC to produce the relatively more pollution-intensive product, whereas countries with lower MACs or more powerful environmental interest groups would produce relatively less pollution-intensive products. These ideas are captured in the "pollution flight" and "pollution haven" hypotheses (Leonard 1988).

10. Summary

This article takes infringements on the environmental security of countries as the point of departure and develops a variety of conceptual lenses to focus on the instruments which governments may choose to achieve environmental goals (see Table 2). Further research is needed to show under which circumstances particular instruments are chosen and when not as well as the impact of changing scientific knowledge, multiple thresholds, and the role of technology on a country's ambitions to abate pollution.

Table 2: **Summary of Instruments**

Type of instrument	Instrument	No.
economic - optimal	Pigouvian tax	(I 1), (I 5)
economic - suboptimal	production restrictions (static and dynamic)	(I 2), (I 6), (I 12)
	taxes on trade	(I 9)
technological	reducing the marginal pollution coefficient of production ("e"), incl. by way of technical cooperation	(I 3), (I 7)
ecological modification	enlarging maximum assimilative capacity of the environment (static and dynamic)	(I 4), (I 11)
	modifying the coefficient of GEC effect on a country	(I 10)
others	relocation of polluting activity (in space)	(I 8)

List of Abbreviations

*	equilibrium
1, 2, 3, ..., n	time indicator subscripts
b	environmental assimilative capacity in a period (constant)
D	demand for the polluting good Y
d	domestic
d->i, i->d	direction of flow (pollutants or trade in goods)
E	amount of the externality
e	marginal externality coefficient
E^{cause}	externality which causes global environmental changes
E^{effect}	externality which are the effects of global environmental changes or of $GEC^{transformed}$
exp	exponential function
f	flow coefficient for transboundary pollutant
g	coefficient of effect of global environmental change
GEC	global environmental change
$GEC^{transformed}$	transformed $GEC^{untransformed}$ which will generate (potentially different) effects on economies
$GEC^{untransformed}$	untransformed E^{cause} summed across all countries
I	instrument for intervention by governments to assure achievement of environmental goal
i	international
ln	natural logarithm
M	imports of Y
MAC	maximum (environmental) assimilative capacity
MAC^{effect}	maximum (environmental) assimilative capacity for effects (global environmental change problems only)
OECD	Organisation for Economic Cooperation and Development
p	price of Y
PPP	polluter pays principle
RE	remaining or non-assimilated externality at the end of a period
S	supply of the polluting good Y
t	Pigouvian tax on the production of Y
w	world
X	exports of Y
$\ddot{y}$	growth rate of Y (per period)
Y	polluting good produced in d and i
Δ	change

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