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MEASURING THE EFFECTIVENESS OF INTERNATIONAL ENVIRONMENTAL REGIMES

by

Carsten Helm & Detlef F. Sprinz

POTSDAM INSTITUTE

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CLIMATE IMPACT RESEARCH (PIK)

Corresponding authors:
Dipl. Pol. Carsten Helm, M.A.
Detlef F. Sprinz, Ph.D.
Potsdam Institute for Climate Impact Research
P.O. Box 60 12 03, D-14412 Potsdam, Germany
Phone: +49-331-288-2557 or 2555
Fax: +49-331-288-2600
E-mail: helm@pik-potsdam.de or dsprinz@pik-potsdam.de

Abstract

While past research has emphasized the importance of international regimes for international governance, systematic assessments of regime effects are missing. This article derives a standardized measurement concept for the effectiveness of international environmental regimes by developing an operational rational choice calculus to evaluate actual policy simultaneously against a no-regime counterfactual and a collective optimum. Subsequently, the empirical feasibility of the measurement instrument is demonstrated by way of two international treaties regulating transboundary air pollution in Europe. The results demonstrate that the regimes indeed show positive effects – but fall substantially short of the collective optima.

Acknowledgments

1. Introduction

In a major review of research on international environmental policy, Zürn concludes that regime effectiveness has become a "driving force in the analysis of international relations."[1] Much of this research has been undertaken in the environmental field. The first phase was characterized by a focus on the conditions which account for the rise of international regimes.[2] However, while international institutions may be successfully initiated, this does not guarantee that they will have effects.

In the second phase of research attention shifted toward regime implementation and compliance.[3] In the present third phase of research on international regimes, we return to the core question whether the international regimes formed actually matter.[4]

In a broader sense, the analysis of regime effectiveness is related to the literature on public policy evaluation.[5] Project evaluation routinely forms part of the standard public policy cycle; it is applied to domestic and comparative political domains such as the evaluation of public health care systems, pension plans and military expenditures. Given the rise of international regimes to combat environmental and other problems on the regional and global scale, it is important for governments to find out which of the international regulatory regimes they have joined actually yield returns on their investments and where progress has been minute. This necessi-

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[1] Michael Zürn, "The Rise of International Environmental Politics: A Review of Current Research," *World Politics* 50 (1998), 649. A similar argument is made by Lisa L. Martin and Beth A. Simmons, "Theories and Empirical Studies of International Institutions," *International Organization* 54 (1998), 729-757.

[2] See Robert O. Keohane, *After Hegemony: Cooperation and Discord in the World Political Economy* (Princeton: Princeton University Press, 1984); Robert O. Keohane and Joseph S. Nye, *Power and Interdependence* (New York, N.Y.: Harper Collins, 1989); Oran R. Young, *International Cooperation: Building Regimes for Natural Resources and the Environment* (Ithaca: Cornell University Press, 1989); Oran R. Young, "The Politics of International Regime Formation: Managing Natural Resources and the Environment," *International Organization* 43(3) (1989), 349-375; Oran R. Young and Gail Osherenko, eds., *Polar Politics - Creating International Environmental Regimes* (Ithaca: Cornell University Press, 1993); Thomas Gehring, *Dynamic International Environmental Regimes: Institutions for International Environmental Governance* (Frankfurt a.M.: Peter Lang, 1994); Volker Rittberger, ed., *Regime Theory and International Relations* (Oxford: Clarendon, 1995); Andreas Hasenclever et al., "Interests, Power, Knowledge: The Study of International Regimes," *Mershon International Studies Review* 40 (October 1996), 177-228.

[3] See Abram Chayes and Antonia H. Chayes, "On Compliance," *International Organization* 47(2) (1993), 175-205; David G. Victor et al., eds., *The Implementation and Effectiveness of International Environmental Commitments: Theory and Practice* (Cambridge, MA: MIT Press, 1998); Edith Brown Weiss and Harold K. Jacobson, eds., *Engaging Countries - Strengthening Compliance with International Environmental Accords* (Cambridge, MA: MIT Press, 1998); Kenneth Hanf and Arild Underdal, eds., *International Environmental Agreements and Domestic Politics* (Aldershot: Ashgate, forthcoming).

[4] Peter Haas, "Do Regimes Matter? Epistemic Communities and Mediterranean Pollution Control," *International Organization* 43(3) (1989), 377-403.

[5] See Lawrence B. Mohr, *Impact Analysis for Program Evaluation*, (Chicago, IL: Dropsy, 1988).

tates both aggregate (regime-wide) assessments as well as disaggregate results on the level of countries. Such a comparison of the relative effectiveness of different regimes serves also as a prerequisite for an inquiry into the causal impacts of various regime design factors.

In this article, we develop a general measurement concept for assessing the degree to which international environmental regimes contribute to environmental problem-solving (Section 2). This concept will subsequently be formalized for the case of transboundary environmental problems (Section 3), and its feasibility is illustrated with data from the regulation of "acid rain" in Europe (Section 4). Furthermore, the article highlights the benefits of an assessment tool for the effectiveness of international environmental institutions by comparing the results with those derived from different methodological approaches.

2.   The General Measurement Concept for Regime Effectiveness

The present literature does not offer a unified approach to assess a regime's effectiveness. Nevertheless, there exists considerable agreement about the conceptual problems. These have been succinctly summarized by Underdal:

> (i) What precisely constitutes the *object* to be evaluated? (ii) Against which *standard* is the object to be evaluated? (iii) *How* do we operationally go about comparing the object to our standard; in other words, what kind of measurement operations do we perform in order to attribute a certain *score* of effectiveness to a certain object (regime)? (emphasis in the original).[6]

The method outlined below systematically builds on each of these questions.

2.1 The object of evaluation

In his literature review on environmental regimes effectiveness, Jacobeit concludes that much research has focused on variables of political behavior in the economic-political domain, the legal-political domain, the comparative political dimension – enhanced by multi-level explanations relating domestic and international environmental policy –, or the processes dimension of international regimes.[7] Probably the most

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[6]   Arild Underdal, "The Concept of Regime 'Effectiveness'," *Cooperation and Conflict* 27(3), (1992), 228-229. Similarly, Thomas Bernauer, "The Effect of International Environmental Institutions: How We Might Learn More," *International Organization* 49(2) (1995, 355) suggests: „The concept of institutional effect raises three questions: Which outcomes do institutions affect and which of these outcomes should analysts focus on? How can these outcomes be evaluated in terms of institutional success or failure? Which measurement operations are required to assess the effect of an institution?".

[7]   Cord Jacobeit, "Wirksamkeit in der internationalen Umweltpolitik [Effectiveness in the Field of International Environmental Policy]," *Zeitschrift für Internationale Beziehungen*, 5(2) (1998), 345-366. On the economic-political domain see Robert O. Keohane and Marc A. Levy, ed., *Institutions for Environmental Aid*, (Cambridge, MA: The MIT Press, 1996); on the legal-political domain Victor et al. (fn. 3); on the comparative political dimension Miranda A. Schreurs and Elizabeth C. Economy, eds., *The Internationalization*

inclusive concept of regime effectiveness has been advanced by Young, who combines several of the above aspects.[8] However, the challenges in devising operational measures of regime effectiveness increase with the comprehensiveness of the underlying concept.

Most authors have indeed used relatively simple indicators as the object of evaluation. An obvious candidate is the degree of problem-solving: the actual *impacts* of a regime. In „Institutions for the Earth", Keohane et al. ask the crucial question: "Is the quality of the environment or resource better because of the institution?"[9] However, reliable data are often lacking. Furthermore, especially for environmental problems there is sometimes a long time lag between the action triggered by a regime and the impacts which follow from this action. This is particularly severe for pollution stock problems, where the recovery process of the environment may last long (as for tropospheric ozone depletion) or the impacts of pollutive activities are felt only after a long time lag (as for climate change).

Such problems are also acknowledged by Keohane et al., who therefore suggest to "focus on observable political effects of institutions rather than directly on environmental impact".[10] This evaluation of a regime along its *output* may take place either on the level of the regime itself, analyzing its norms, principles and rules,[11] or on the national level in terms of the regulations and other decisions which have been agreed by the members of the regime. However, a high political output does not necessarily lead to the desired impacts, because rules may prove ineffective or simply be neglected.

We therefore believe that a policy instrument which lies in between those two extremes, and covers aspects of both of them, will be the most appropriate object of evaluation. This policy instrument should be closely related to the primary goals of an institution, and sufficient reliable data must be available. In many of the most prominent environmental regimes, emission reductions (of greenhouse gases, CFCs, SO_2 or NO_x) will be an obvious candidate, because they follow more or less directly from the political output of the regime and are deterministically or at least probabilistically related to environmental impacts. This is in line with the conclusions by Zürn and Jacobeit, both of which regard emission-based approaches to the measurement of international regime effectiveness as particularly promising.[12]

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of Environmental Protection, (Cambridge: Cambridge University Press, 1997); and on the processes dimension Sebastian Oberthür, *Umweltschutz durch internationale Regime: Interessen, Verhandlungsprozesse, Wirkungen* [Environmental Protection Resulting from International Regimes: Interests, Negotiation Processes, Impacts] (Opladen: Leske+Budrich, 1997).

[8] Oran R. Young, ed., *The Effectiveness of International Environmental Regimes: The Causal Connections and Behavioral Mechanisms* (Cambridge, MA: MIT Press, forthcoming).

[9] Robert O. Keohane, Peter M. Haas and Marc A. Levy, "The Effectiveness of International Environmental Institutions," in Haas et al., eds., *Institutions for the Earth: Sources of Effective International Environmental Protection* (Cambridge, MA: MIT Press 1993), 7.

[10] Ibid.

[11] See Underdal (fn. 6), 230.

[12] Zürn (fn. 1), 830 and Jacobeit (fn. 7), 348.

2.2 The standard of evaluation

Having decided on the object of evaluation, the next question is against which *standard* this object should be evaluated. The first candidate is the no-regime counterfactual or "the hypothetical state of affairs that would have come about had the regime not existed."[13] Despite its widespread use in the literature, there is a common feeling of uneasiness in doing so.[14] For example, Bernauer criticizes that the counterfactual component „introduces an element of more or less informed speculation" – hence one is very much tempted to ask whether one can do without it.[15]

However, Fearon has convincingly argued that counterfactuals cannot be avoided in nonexperimental hypothesis testing and all one can do is to be explicit and careful in their use.[16] Similarly, Tetlock and Belkin summarize a recent volume on „Counterfactual Thought Experiments in World Politics" by concluding that „we can avoid counterfactuals only if we eschew all causal inference."[17] It is the identification of effects which have been *caused* by a regime that constitutes the very essence of research on regime effectiveness.

To give an example, the observation that SO_2 emissions in Eastern Europe have dropped significantly in the decade after conclusion of the 1985 Helsinki Sulfur Protocol (see below) does not suffice to establish any causal link between the two events. A priori it may well be that virtually all those emission reductions are a consequence of the collapse of Eastern European economies rather than of any international regime. Only after we have systematically explored the counterfactual of what would have happened without the regime can we subscribe the remaining effects to the international regime.

Having accepted the indispensability of counterfactual reasoning in any analysis of regime effectiveness, the main challenge is to find methods by which its „speculative element" can be minimized. Many studies of regime effectiveness in the field of international environmental policy employ process tracing in order to establish causal effects of international regimes.[18] By familiarizing themselves with the subject matter, expert authors try to "verstehen" (understand) the role which international regimes play across their life cycle. However, the subjective component of the particular researcher figures strongly in this approach and, as Zürn concludes, "[t]he reader ... wonders whether the method could not be made more systematic."[19]

An alternative approach is to explicitly model regime and non-regime factors – and thereby construct a tool to simulate different states of the world. This exercise is

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[13] Underdal (fn. 6), 231.

[14] See Philip E. Tetlock and Aaron Belkin, ed., *Counterfactual Thought Experiments in World Politics - Logical, Methodological, and Psychological Perspectives* (Princeton, N.J.: Princeton University Press, 1996).

[15] Bernauer (fn. 6), 360.

[16] James D. Fearon, "Counterfactuals and Hypothesis Testing in Political Science," *World Politics* 43 (1991), 169-195.

[17] Tetlock and Belkin (fn. 14), 3.

[18] Examples are Arild Underdal, *Patterns of Effectiveness: Examining Evidence from 13 International Regimes*, Paper presented at the 38th Annual Convention of the International Studies Association (Toronto, Ontario, 1997) and Young (fn. 8).

[19] Zürn (fn. 1), 640.

still in its infancy and has probably not yet reached a stage where it can be implemented reliably for complex policy issues.[20] On the other hand, the simulation of baseline scenarios of emission trajectories has become a standard exercise in many environmental policy areas. Systematic assessment of those scenarios and their ex-post correction using the actual development of critical parameters (such as population and GDP growth) may offer some guidance in constructing no-regime counter-factuals.

In this article we have opted to seek advice from a number of long-standing policy experts in the particular domain under investigation and elicit their best assessment of the no-regime counterfactual via standardized interviews (see Section 4). The presumption behind this approach is that the assessment of the counterfactual should be undertaken on the basis of the best knowledge available in a particular field. Furthermore, by interviewing different groups of actors, this method makes it possible to incorporate different perspectives and, by averaging their statements, derive estimates that are less biased towards the subjective assessment of any particular individual. However, it is important to note that the quality of the data derived from interviews impacts on the substantive findings on regime effectiveness. In conclusion, we believe that progress in the construction of counterfactuals is probably the most pressing area of improvement not only for the viability of the approach followed in this article, but for any study on regime effectiveness.

The no-regime counterfactual does not suffice as the only evaluative criteria, because it gives only a very vague indication how well a regime serves the purpose it has been designed for. For example, some environmental problems might require higher aggregate reductions of pollutive emissions than others, an important aspect which would be neglected if the effectiveness of a regime were only judged according to changes relative to the no-regime counterfactual. Evaluating a regime „against some concept of collective optimum"[21] circumvents such problems; however, its specification poses a research challenge by itself.

One avenue followed by the compliance literature is to use the targets specified in environmental treaties. However, this approach causes an endogeneity problem, because the attainment of modest treaty targets would be mistaken as an indicator of high regime effectiveness. As Downs et al. observe, severe selection effects may have led researchers to find high degrees of compliance when - in fact - the „treaty's depth of cooperation,"[22] that is the incentives for countries to defect from an international environmental agreement, are low.

Bernauer proposes to use broader institutional goals instead.[23] However, not only the specification of explicit treaty targets but also the setting of broader institutional goals is part of the regime process and, therefore, susceptible to the endoge-

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[20] This is not to deny recent advances in this area, e. g. in the literature on two-level games or domestic-policy models. Examples are Robert Pahre and Paul A. Papayoanou, "New Games: Modeling Domestic-International Linkages," special issue of the *Journal of Conflict Resolution* 41(1) (1997); Jongryn Mo, „The Logic of Two-level Games with Endogenous Domestic Coalitions," *Journal of Conflict Resolution* 38(3) (1994), 402-422.

[21] Underdal (fn. 6), 231.

[22] George W. Downs et al., "Is the Good News About Compliance Good News About Cooperation?" *International Organization* 50(3) (1996), 383.

[23] Bernauer (fn. 6), 369.

neity problem. Furthermore, broader institutional goals are often formulated very vaguely – like the objective „to prevent a dangerous anthropogenic interference with the climate" in the United Nations Framework Convention on Climate Change (UNFCCC) – so as to assure that the goals will be widely acceptable. This vagueness makes it extremely difficult to derive clear-cut evaluative criteria.

In those cases where ecosystems are characterized by large discontinuities in their response to pollutants, thresholds like the critical loads concept for acid rain could be used as the collective optimum. If environmental vulnerability has been eliminated, then a collective optimum is reached. In the context of transboundary air pollution, policies aim towards avoiding the exceedance of critical loads, which are defined as:

> a quantitative estimate of the exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge.[24]

However, not only do many environmental problems lack such discontinuities which qualify as obvious environmental optima, but from a welfarist perspective attainment of the environmental optimum is not necessarily desirable. To take a somewhat extreme example, developing a world-wide protection system against asteroids seems prohibitively expensive, even though most of us would agree that it were a good thing in principle.

In conclusion, the best evaluative criteria which represents the collective optimum is provided by another counterfactual, namely the hypothetical state of affairs that would have come about with a perfect regime. While constructing this second counterfactual may appear demanding at first sight, in Section 3 we present a method how it can be derived by game-theoretical reasoning from knowledge of the no-regime counterfactual.

2.3. Defining and Operationalizing Regime Effectiveness

In order to assess a regime's effectiveness, we have previously suggested to incorporate a no-regime counterfactual as well as a collective optimum as standards of evaluation. In combination with our comments on the object of evaluation, this can by synthesized into the following measurement concept for regime effectiveness:

Regime effects are improvements in the object of evaluation (dependent variable) that can be attributed to the regime. Usually this will be evaluated along the degree of instrument use such as percentage emission reductions. A lower bound is determined by the *no-regime counterfactual (NR)* (see Figure 1): the degree of instrument use that would have occurred in the absence of the international regime under investigation. An upper bound is established by the *collective optimum (CO)*: the degree of instrument use that would have been obtained by a perfect regime. Accordingly, the *regime potential* is the distance between the no-regime counter-

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[24] UNECE, Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution Concerning the Control of Emission of Nitrogene Oxides or Their Transboundary Fluxes (Geneva: United Nations Economic Commission for Europe, 1998), Article 1(7).

factual (NR) and the collective optimum (CO), expressed in units of instrument use. Usually, countries (or a group of countries) will execute *actual policies (AP)* which fall into this interval. The *effectiveness of a regime (E)* can then be measured as the relative distance that the actual performance has moved from the no-regime counterfactual towards the collective optimum, or as the percentage of the regime potential that has been achieved (see Figure 1). This score falls into the interval [0, 1].

By construction of the effectiveness score, a small regime potential *(CO – NR)* would imply that even small deviations of either the no-regime counterfactual, the collective optimum or the actual performance can lead to relatively large changes in the results. To assess this effect, we define this *sensitivity of effectiveness score (S)* as the absolute change of the effectiveness score resulting from a change in either the actual performance or the no-regime counterfactual by 1 percentage point.

This definition and measurement concept of regime effectiveness shows a range of advantages: By merging the two evaluative criteria of relative improvements from the no-regime counterfactual and distance from the collective optimum into one dimension, we overcome the bias towards either of the two, which characterizes large parts of the literature on regime effectiveness.[25] Furthermore, the measurement concept is expressed in very general terms and it is not limited to a particular policy instrument or a specific method to derive the upper and lower bounds. The appropriate method to be chosen depends on a variety of factors, including the type of international regime, data availability, and the methodological orientation of researchers. By providing a common standard of evaluation which can be used by researchers from different schools of international relations, the communication and comparison of results is facilitated. Finally, the effectiveness scores are easy to interpret in the applied context by policy-makers.

NR   AP   CO

degree of instrument use
(emission reductions in %)

Effectiveness Score $E = \dfrac{AP - NR}{CO - NR}$

Sensitivity of Effectiveness Score $S = \dfrac{AP + 1 - NR}{CO - NR} - E = \dfrac{1}{CO - NR}$

Notes: NR = no-regime counterfactual
          CO = collective optimum
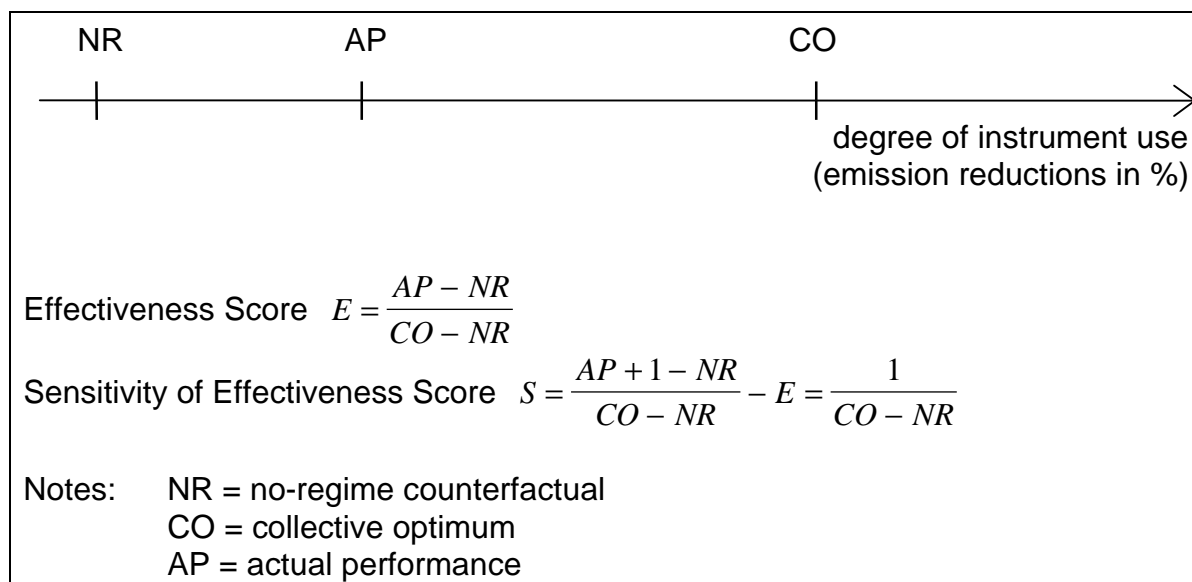   AP = actual performance

Figure 1: Measuring Regime Effectiveness – The General Concept

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[25] See Underdal (fn. 6), 230-234.

3. A Rational-Choice Approach to Measure Regimes Effectiveness

Based on the general measurement concept for regime effectiveness, we will introduce a formal modeling approach to demonstrate how the no-regime counterfactual and the collective optimum can be determined. In line with the empirical example presented in Section 4, we develop the solution for transboundary environmental regimes; however, the extension to many other problems of international cooperation is fairly straightforward.

We perceive of states as self-interested actors, which choose their strategies in accordance with the principal goal of maximizing their individual payoffs. Strategies are defined in terms of instrument use such as pollutive emissions or emission reductions respectively. Payoffs are measured as the difference between the (political) benefits and costs of emissions reductions. However, the goal-seeking behavior is effected by the strategic interdependency of the international system. This arises from the fact that national depositions, that is the total pollution leading to environmental damages in a country, do not only originate from one's own emissions but also from emission exports by other countries. As a consequence, national strategies have to simultaneously take national and foreign sources of environmental damages into account and optimize their national emission (reduction) policy accordingly.[26]

This simple game-theoretic description of transboundary environmental problems leads to a straightforward interpretation of the no-regime counterfactual and the collective optimum. In particular, the *no-regime counterfactual* can be interpreted as the non-cooperative solution of the transboundary pollution game that would follow from the uncoordinated choice of one's best reply to the strategies of the other countries (Nash-equilibrium). In choosing their emissions levels, states would take only those emissions into account which are deposited in their own country and neglect the damaging effect of their exported emissions to other countries.

Stated more formally, each country, indexed alternatively by *i* and *j*, follows the objective of minimizing its own "total (political) costs" of pollutive emissions:[27]

$$\min_{E_i} C_i(E_i) + p_i D_i(L_i) \cdot \tag{1}$$

$C_i(E_i)$ are the abatement costs of reducing emissions to the level E_i; following standard assumptions, marginal cost of emission reductions increase with the level of abatement. Environmental damages $D_i(L_i)$ are assumed to increase exponentially in the exceedance of critical loads L_i. This is calculated as the difference of depositions and the level of critical loads L_i^*, where depositions depend on emissions and the transboundary transport coefficients t_{ji}. The latter specify the share of emissions

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[26] James D. Morrow, *Game Theory for Political Scientists* (Princeton: Princeton University Press Morrow, 1994) is an excellent introduction to game theory for political scientists.

[27] It is more convenient to use emissions rather than emission reductions as the choice variable, because the latter would require specification of a baseline relative to which emissions are reduced. A similar problem formulation as in the following, but without explicit consideration of critical loads, can be found in Karl-Göran Mäler, "The Acid Rain Game," in Henk Folmer and E. v. Ierland, eds., *Valuation Methods and Policy Making in Environmental Economics* (Amsterdam: Elsevier, 1989), 231-252.

from country j that is deposited in i. Taking into account that no damages occur if the exceedance of critical loads is reduced to zero, this can be expressed as

$$L_i = \sum_{j \in N} E_j t_{ji} - L_i^* \qquad \text{and} \qquad D_i(L_i) = \begin{cases} L_i^b & \text{if } L_i > 0 \\ 0 & \text{if } L_i \leq 0 \end{cases}. \qquad (2)$$

It remains to explain the term p_i in equation (1). While governments are assumed to pursue policies in accordance with optimality criteria such as the equalization of marginal abatement and damage costs, they are dependent on domestic political pressure in choosing their policies. In particular, they are endogenous to pro-environmental political actors favoring strong emission reductions and to pressure from industries worrying about abatement costs. Introducing this domestic political component[28] into the measurement concept of regime effectiveness provides both a heuristic in determining the empirical values for the no-regime counterfactual (see Section 4) as well as a bridge to the literature on multiple-level analysis.[29] In substantive terms, the influence of political pressure groups, which in turn is a function of their political capabilities and issue salience, is represented by the weighting factor p_i that signifies the relative political preponderance of pro-environmental forces vis-à-vis opposing interests.[30]

If each country minimizes national total cost of emissions, the optimality conditions are derived by differentiating the objective function (1) with respect to emissions, yielding (for $L_i > 0$)

$$-\partial C_i / \partial E_i = b p_i t_{ii} L_i^{b-1}. \qquad (3)$$

This is the standard non-cooperative Nash-solution where countries choose their optimal emission level such that their marginal abatement costs of emissions are equal to the corresponding marginal benefits of avoided damages in their own country. Furthermore, emission reductions are contingent on political pressure p_i and are zero once the assimilative capacity of a country is not exceeded $(L_i \leq 0)$.

In contrast, the cooperative solution is obtained if each individual country i chooses its emission level E_i so as to minimize the joint total cost of pollutive emissions in all countries. Thus, the objective function becomes

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[28] See Manuel Pastor and Carol Wise, "The Origins and Sustainability of Mexico's Free Trade Policy," *International Organization* 48(3) (1994), 459-489; Detlef F. Sprinz, *Why Countries Support International Environmental Agreements: The Regulation of Acid Rain in Europe*, Ph.D. diss (Ann Arbor: The University of Michigan, 1992), ch. 6.

[29] See Peter B. Evans, Harold K. Jacobson and Robert D. Putnam, eds., *Double-Edged Diplomacy: International Bargaining and Domestic Politics* (Berkeley, CA: University of California Press, 1993; Keisuke Iida, "When and How Do Domestic Constraints Matter? Two-Level Games with Uncertainty," *Journal of Conflict Resolution* 37(3) (1993), 403-426. See also fn. 20.

[30] Note that we have normalized the political pressure by actors concerned about abatement cost to equal 1 so that *p* must be interpreted as the *relative* political pressure of environmental pressure groups. Thus, it can be compared with the role of relative prizes in economic models.

$$\min_{E_i} \sum_{j \in N} \Big[C_j(E_j) + p_j D_j(L_j) \Big],$$ (4)

with the first order conditions for optimality

$$- \partial C_i / \partial E_i = \sum_{j \in N} b p_j t_{ij} L_j^{b-1}.$$ (5)

The summation sign implies that in the cooperative solution emission exports and their damages to other countries are fully taken into account, and each country reduces emissions until its marginal abatement costs are equal to the sum of marginal benefits of avoided environmental damages caused by those emissions in all countries. This can be interpreted as the *collective optimum* because it would be the optimal choice of the international community acting as a unitary actor. Obviously, it implies higher abatement costs and accordingly higher emission reductions as compared to the no-regime counterfactual.

The function of a regime is to overcome the collective action problem which follows from the transboundary character of emissions and to enable countries to enter into mutually beneficial agreements.[31] The factors *explaining* a regime's degree of effectiveness are not explored in this article, and therefore we are not interested how cooperation could be sustained as an equilibrium outcome. Yet, we argue that the non-cooperative and the cooperative solution are appropriate yardsticks to evaluate a regime's effectiveness. Indeed, they are related to each other in a very elegant way. Once the no-regime counterfactual has been estimated, the collective optimum – which is in principle another counterfactual representing a perfect regime based on the same preference ordering that underlies the no-regime counterfactual – can be derived straightforwardly via theoretical reasoning. Thereby, consistency of the two evaluative criteria with each other is assured.

By assessing the relative position of the actual performance in between those two points, effectiveness scores can be derived straightforwardly according to the general measurement concept introduced above (see Figure 1). This can be undertaken for individual countries, yielding country-specific regime effectiveness scores, as well as for the aggregate of all countries, yielding the overall effectiveness of the transboundary regime. In contrast to the compliance literature, this approach includes the effects of international regimes on non-signatory countries. Thereby, the selection effect between signatory and non-signatory countries – with the latter expected to be less "compliant" than the former group – is avoided. Since the group of all countries effects the environmental quality of a biogeographical region, omission of non-signatory countries may seriously bias research findings.

4. The Effectiveness of the European Regime for Transboundary Air Pollution

Building on the derivation of the measurement concept of regime effectiveness for transboundary pollution problems in the previous section, we will demonstrate its

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[31] Keohane (fn.2); Duncan Snidal, „The Game Theory of International Politics," in Kenneth A. Oye *Cooperation Under Anarchy* (Princeton: Princeton University Press, 1986), 25-57.

empirical usefulness with the help of an example from the various policies to reduce transboundary air pollution in Europe during the 1980s and early 1990s.

While localized air pollution problems have been known ever since early industrialization, transboundary air pollution problems have attracted public and scientific attention more recently. In the wake of hypotheses of damages to lakes, forests, buildings and public health resulting from acidifying pollutants, such as sulfur dioxide (SO_2) and nitrogen oxides (NO_x), an international regime has been formed during the late 1970s within the United Nations Economic Commission for Europe (UNECE) to regulate the emission of these pollutants. Besides acidification, problems related to eutrophication (oversupply of nutrients), tropospheric ozone episodes, heavy metals and persistent organic compounds have been regulated following the 1979 Convention on Long-Range Transboundary Air Pollution (LRTAP).[32]

Of particular interest are two international environmental agreements which permit an evaluation of past accomplishments, namely the 1985 Helsinki Protocol to the 1979 LRTAP-Convention and the 1988 Sofia Protocol.[33] Whereas the Helsinki Protocol requires signatory countries to reduce their sulfur dioxide emissions or transboundary fluxes by 30 percent until 1993 relative to their 1980 emissions, the Sofia Protocol requires signatories to control their nitrogen oxide emissions or their transboundary fluxes such that their 1994 values are no higher than those in 1987. In addition, eleven countries have signed a declaration which obliges them to reduce their NO_x emissions in the order of 30 per cent by 1998 in comparison to any base year chosen between 1980 and 1986. Among the European members of this international regime for transboundary air pollution, some countries did not sign the Helsinki Protocol, while the Sofia Protocol enjoys close to universal support. In part, this differential support for international regulations has been the subject of heated domestic political debates.

4.1 Data Sources

In the following, we will summarize how the various components of the measurement concept for transboundary pollution problems have been operationalized to compute actual effectiveness scores for the two Protocols. As temporal domains, we use the base and target years of the Helsinki Sulfur Protocol (1980 and 1993) and the Sofia NO_x Protocol (1987 and 1994). Data on emissions, depositions, criti-

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[32] UNECE, *Convention on Long-Range Transboundary Air Pollution* (Geneva: United Nations Economic Commission for Europe, 1979). For a detailed introduction to the transboundary air pollution and its regulation in Europe see Sonja Boehmer-Christiansen and Jim Skea, *Acid Politics - Environmental and Energy Policies in Britain and Germany* (London: Belhaven Press, 1991); Marc A. Levy, „European Acid Rain: The Power of Toteboard Diplomacy," in Peter M. Haas et al. (fn. 9), 75-132; Sprinz (fn. 28), ch.4, as well as Detlef Sprinz and Tapani Vaahtoranta, „The Interest-Based Explanation of International Environmental Policy," *International Organization* 48(1) (1994), 77-105.

[33] UNECE, *Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution on the Reduction of Sulfur Emissions or Their Transboundary Fluxes by at Least 30 Percent* (Geneva: United Nations Economic Commission for Europe, 1985); UNECE, *Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution Concerning the Control of Emission of Nitrogene Oxides or Their Transboundary Fluxes* (Geneva: United Nations Economic Commission for Europe, 1988).

cal loads, transport coefficients of transboundary emission flows and marginal abatement costs are available from the Cooperative Programme for Monitoring and Evaluation of Air Pollutants in Europe (EMEP)[34] and the RAINS (Regional Acidification INformation and Simulation) model developed at the International Institute for Applied Systems Analysis (IIASA).[35]

However, neither data about the relative political preponderance of pro-environmental pressure groups nor crossnational damage cost estimates are available.[36] This problem is quite common, because the cause-effect chain of emissions and environmental impacts is often insufficiently understood, and the valuation of impacts by the society is difficult to assess, especially for non-tangible values such as biodiversity and impacts on human health.[37] Therefore, we have solicited expert judgments to assess emission reductions of the no-regime counterfactual.

For SO_2, country teams in Finland, Germany, Hungary, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom have conducted standardized interviews with at least one senior policy expert from each of the following three groups: governmental organizations, environmental NGOs, and academia.[38] To increase the reliability of results and to include all countries in the biogeographical region (see Table 1), the same questions have been presented to a long-standing expert in the field of the LRTAP regime. If the estimates of these two sources differed, the arithmetic average has been taken. For NO_x, only estimates of the long-standing expert were available, and those results should therefore be interpreted with caution.

Interpreting the estimates for the no-regime counterfactual as the Nash equilibrium of the non-cooperative game, they can be used to infer marginal abatement costs and in turn also the corresponding marginal damage costs, as the two must be equal in equilibrium (see equation 3).[39] The resultant marginal damage costs are interpreted as "the revealed preference of the governments and parliaments for reductions in emissions of sulphur".[40] This concurs with the inclusion of political pressure groups into countries' payoff functions as elaborated in the previous section.

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[34] Kevin Barrett and Erik Berge, *Transboundary Air Pollution in Europe: EMEP/MSC-W Status Report 1996* (Oslo: The Norwegian Meterological Institute, 1996). For details on data sources, see Appendix A.

[35] Joseph Alcamo, Roderick Shaw and Leen Hordijk, eds., *The RAINS Model of Acidification: Science and Strategies in Europe* (Dordrecht: Kluwer Academic Publishers, 1990). For a discussion of uncertainties and their implications for negotiations see Carsten Helm, „International Cooperation Behind the Veil of Uncertainty: The Case of Transboundary Acidification," *Environmental and Resource Economics* 12 (1998), 185 – 201.

[36] C. A. Cough et al., „Environmentally Targeted Objectives for Reducing Acidification in Europe," *Energy Policy* 22(12) (1994), 1055-1066.

[37] See Per-Olov Johansson, *Cost-Benefit Analysis of Environmental Change* (Cambridge, UK: Cambridge University Press, 1993).

[38] See Detlef Sprinz, Carsten Helm, Rudy Lewanski and Kenneth Hanf, International Governmental Organizations and National Participation in Environmental Regimes: The Organizational Components of the Acidification Regime, Final Report (mimeo, 1998).

[39] See Mäler (fn. 27) and Helm (fn. 35).

[40] Karl-Göran Mäler, „Incentives in International Environmental Problems," in Horst Siebert, *Environmental Scarcity* (Tübingen: Mohr, 1991), 81.

In order to determine the cooperative solution, marginal damage costs for the complete domain of emission levels are needed. Due to the absence of reliable empirical estimates, we had to make assumptions concerning the shape of the damage cost function. One possibility is to assume that damage costs increase linearly in emissions.[41] While this considerably simplifies the analysis, it would imply that the choice of optimal reduction levels were independent of the associated changes in the state of the environment. This can be easily seen by setting the exponent b in equations (3) and (5) equal to one so that marginal damage costs would be constant. Therefore, we suggest a quadratic functional form of damage costs *(b = 2),* which has been widely used in the literature.[42] This specification makes each country's emission reductions dependent on the emission reductions of the other countries: the larger the reduction of imported depositions, the lower the incentive to reduce one's own emissions (see equation (5)). Therefore, equation (5) has been solved simultaneously for all countries included in the analysis.[43]

4.2 Empirical Findings

By applying the calculi from the previous section to the data on transboundary air pollution regulations in Europe, we arrive at the measure of regime effectiveness (see Table 1). The aggregated effectiveness score is 0.39 for the SO_2-regime and 0.31 for the NO_x-regime, as compared to a permissible range of [0,1]. By contrast to the compliance literature which would emphasize the high degree of covariation between legal obligations and the emission reductions accomplished among signatory countries, the aggregated regime effectiveness scores are substantively larger than zero in both pollutant domains but fall short of their theoretical maximum. It is also striking that the overall regime effectiveness scores for both pollutants are of a similar order of magnitude.

Turning to the country-specific effectiveness scores, it should be noted that some of the environmentally most concerned countries (like Austria, Norway, Sweden, Finland, and Switzerland for SO_2) have reduced their emissions in excess of those required in the cooperative solution. This may result from the very high noncooperative reductions, the fact that these countries are no major emission exporters, and, most importantly, from the substantial improvements in the state of their environment through emission reductions in *other* countries. In combination, those effects lead to the initially counterintuitive result that actual emission reductions are higher than in the cooperative solution: These countries clearly have taken a leadership function.

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[41] See Mäler (fn. 27).
[42] See William J. Baumol and Wallace Oates, *The Theory of Environmental Policy* (Cambridge, UK: Cambridge University Press, 1988).
[43] For details on this procedure, see Appendix B.

Results for SO_2-Emissions

Countries	AT	BE	BG	CS	DK	FI	FR	DE	GR	HU	IE	IT	NL	NO	PL	PT
Non-cooperative reductions (NR)	80	60	30	35	60	60	65	54	-30	32	20	38	63	70	30	-20
Actual reductions (AP)	82	64	31	43	65	79	66	58	-28	54	29	61	67	74	34	-13
Cooperative reductions (CO)	80	76	73	72	69	64	80	67	49	67	48	51	77	70	54	-8
Effectiveness Score (E)	1*	0.28	0.01	0.21	0.55	1*	0.08	0.33	0.03	0.62	0.33	1*	0.31	1*	0.15	0.59
Sensitivity of Score (S)	n. d.	0.06	0.02	0.03	0.11	0.24	0.07	0.07	0.01	0.03	0.04	0.08	0.07	n. d.	0.04	0.08

Countries	RO	ES	SE	CH	UK	YU	RU	UA	BY	All
No-regime counterfactual (NR)	65	23	76	55	29	0	45	40	40	41
Actual performance (AP)	68	38	80	71	35	54	52	43	41	49
Collective optimum (CO)	65	57	76	56	71	46	53	51	81	62
Effectiveness Score (E)	1*	0.44	1*	1*	0.14	1*	0.86	0.27	0.04	0.39
Sensitivity of Score (S)	n. d.	0.03	n. d.	0.92	0.02	0.02	0.13	0.09	0.02	0.05

Results for NO_x-Emissions

Countries	AT	BE	BG	CS	DK	FI	FR	DE	HU	IE	IT	NL	NO	PL	PT	RO
No-regime counterfactual (NR)	20	-9	21	42	5	0	5	15	25	-7	-8	6	-8	25	-75	-20
Actual performance (AP)	24	-9	21	46	10	2	7	20	31	-6	-8	12	5	28	-74	-20
Collective optimum (CO)	20	10	22	42	19	15	17	25	27	15	-7	21	14	29	-45	31
Effectiveness Score (E)	1*	0	0	1*	0.35	0.14	0.17	0.52	1*	0.05	0	0.40	0.60	0.69	0.03	0
Sensitivity of Score (S)	n. d.	0.05	1.94	n. d.	0.07	0.07	0.08	0.10	0.44	0.05	1.41	0.07	0.05	0.23	0.03	0.02

Countries	ES	SE	CH	UK	YU	RU	UA	BY	All
No-regime counterfactual (NR)	-38	3	19	11	8	18	43	18	11
Actual performance (AP)	-38	10	20	13	8	25	48	23	14
Collective optimum (CO)	-20	19	42	29	15	18	62	37	21
Effectiveness Score (E)	0	0.45	0.04	0.11	0	1*	0.26	0.26	0.31
Sensitivity of Score (S)	0.06	0.06	0.04	0.06	0.15	n. d.	0.05	0.05	0.10

Table 1:   The Effectiveness of the LRTAP-Regime

Notes: (a) Country codes: Austria (AT), Belgium (BE), Bulgaria (BG), (former) Czechoslovakia (CS), Denmark (DK), Finland (FI), France (FR), Federal Republic of Germany (DE), Greece (GR) (due to missing data only for SO_2), Hungary (HU), Republic of Ireland (IE), Italy (IT), the Netherlands (NL), Norway (NO), Poland (PL), Portugal (PT), Romania (RO), Spain (ES), Sweden (SE), Switzerland (CH), United Kingdom (UK), (former) Yugoslavia (YU), Russian Federation (European part) (RU), Ukraine (UA) and the Republic of Belarus (BY).

(b) Figures in the first three rows are reductions in percentage points for the periods 1980-93 (Helsinki Sulfur Protocol) and 1987-94 (Sofia NO_x Protocol). Negative emission reductions represent increases in emissions.

(c) The definition of the effectiveness score and its sensitivity can be found in Figure 1. Countries for which actual performance entails higher reductions than in the collective optimum have been assigned the score "1*", indicating that they have done more than would have been required in the optimal cooperative solution.

(d) If the no-regime counterfactual and the collective optimum are identical, calculation of the sensitivity of effectiveness score would require division by zero. This has been marked "n. d." (not defined).

The indicator of the sensitivity of effectiveness scores shows that the results for most countries are quite robust and (modest) measurement errors would not lead to disproportional changes in effectiveness scores. There are some notable exceptions such as Italy and Bulgaria for the NO_x-regime. Overall, results for SO_2 (sensitivity score = 0.05) are considerably less sensitive to measurement errors than those for NO_x (sensitivity score = 0.10).

In addition to our previous remarks, the overall results depend on the functional specification of damage functions. Table 2 clearly shows that a linear (rather than a quadratic) shape of the damage cost functions would lead to substantively lower effectiveness scores. While these effectiveness scores would still be larger than zero, they appear less realistic because changes in the exceedance of critical loads resulting from emission reductions would be neglected.

Furthermore, in the formulation of the payoff functions it has been assumed that the regime is exclusively driven by a concern for reducing environmental problem pressure. It is, however, likely that other issues have also played an important role in the LRTAP regime. Probably the most important issue are interests to "level the playing field" so as to avoid the adverse effects of environmental regulation on international competitiveness.[44]

Finally, it should be noted that the RAINS abatement costs functions have been criticized especially for the Central and Eastern European countries. A study which, in contrast to the RAINS model, also takes into account the possibility of fuel switching, efficiency improvements, and energy conservation measures finds considerably lower abatement costs.[45] Therefore, the very high effectiveness scores for some Central and Eastern European countries should be regarded with caution, as they may partly result from overestimated abatement costs. These countries under-

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[44] See Carsten Helm, „Transboundary environmental problems and new trade rules," *International Journal of Social Economics*, 23(8) (1996), 29-45.

[45] Otto Rentz et al., *Strategies for Reducing Emissions and Depositions in Central and Eastern European Countries: An Integrated Analysis for International Strategies*, Report Number UBA-FB 104 04 010 (Karlsruhe: Institute for Industrial Production, 1995).

	SO_2				NO_x			
functional form	non-coop ER	actual ER	coop ER	effectiv. Score	non-coop ER	actual ER	coop ER	effectiv. score
linear	41	49	76	0.24	11	14	45	0.11
quadratic	41	49	62	0.39	11	14	21	0.31

Note: ER = emission reductions in percentage points for the periods 1980-93 (Helsinki Sulfur Protocol) and 1987-94 (Sofia NO_x Protocol).

Table 2: Quadratic and Linear Damage Functions Compared (Aggregate Findings)

went major economic transitions in the early 1990s, which have not been fully anticipated in the RAINS model.[46]

This research concludes that the LRTAP regime had discernible effects on the aggregate behavior of countries for reducing sulfur and nitrogen dioxide emissions in the 1980s and early 1990s – with considerable variation across countries. For comparison with our results, only Gehring and Levy provide more detailed assessments of the effectiveness of the LRTAP regime.[47] Gehring concludes that the most pronounced effects of the LRTAP regime consist of (i) including the East Central European countries into a regulatory structure during the time of the cold war in Europe and (ii) domestic political mobilization in some non-signatory countries of the Helsinki Sulphur Protocol (esp. the U.K., Spain, and Poland).[48] The second aspect also holds for countries whose nitrogen dioxide emissions are increasing.[49] Ultimately, Gehring's argument on effectiveness rests on measures of the degree of compliance with international obligations rather than a measure of regime effectiveness.

By contrast, Levy uses qualitative counterfactual analysis to group countries according to the degree of regime effects.[50] In comparing his results with those presented in Table 1, both studies agree that some countries show pronounced regime effects for sulfur emission reduction (such as the former Soviet Union and Denmark), but there is also considerable disagreement for other countries (such as Portugal and Spain). Some of these differences seem to stem from (i) the lack of a systematic counterfactual for all countries along the same dimension of instrument use and from (ii) the omission of developing a collective optimum in Levy's procedure. Only if the lower and upper bounds of the regime potential for each country are developed systematically, cross-nationally comparable results become feasible.

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[46] It has to be noted that in the ex-post estimates of the no-regime counterfactual, the policy experts took the impact of deindustrialization in Central and East-Europe after 1989 on emission reductions into account.

[47] Thomas Gehring, „Das internationale Regime über weiträumige grenzüberschreitende Luftverschmutzung [The International Regime on Long-Range Transboundary Air Pollution]," in Thomas Gehring and Sebastian Oberthür, eds., *Internationale Umweltregime: Umweltschutz durch Verhandlungen und Verträge* [International Environmental Regimes: Environmental Protection Resulting from Bargaining and Agreements] (Opladen: Leske+Budrich), 45-62; Levy (fn. 32).

[48] Gehring (fn. 47), 59.

[49] Ibid., 60.

[50] Levy (fn. 32), 115-127.

On the methodological side, the study by Underdal resembles most closely our approach by using an explicit numerical measurement technique.[51] In his analysis of 15 regimes and a total of about 45 phases,[52] Underdal reports "highly preliminary findings" that, on average, scores of 0.69 (on a scale ranging from 0 to 1) are achieved if a behavioral change concept is employed and 0.41 if progress towards technically optimal solutions is assessed. However, most of the scales appear truncated and lack symmetry,[53] and the coding procedures do not clearly show how the (inter-)calibration *between* regimes is accomplished.

5. Concluding Remarks

The question if regimes matter has been widely discussed in the international relations literature. This article provides a systematic tool to assess the effectiveness of international environmental institutions. By carefully deriving a no-regime counterfactual and a collective optimum, the performance of international institutions can be assessed. This measurement procedure offers two major advantages in comparison to conventional qualitative studies on effectiveness. First, the method and the underlying assumptions have been clearly described, thereby confining the room for hidden subjective judgments to a minimum. Second, the standardized method lends itself to the comparison of the effect of different regimes such as international river pollution, international transport of hazardous waste, and transboundary health problems. Eventually, the measurement concept might even be applied to problems outside the domain of environmental policies. Comparative research would not only probe the generalizability of the measurement concept, but it is also of particular use to public policy: It allows scarce resources to be allocated between less effective and more effective regimes.

The research presented in this article also makes a contribution to the debate between scholars working in the neo-realist and neo-liberal institutionalist traditions. Since neo-realist scholars are particular pessimistic about the effect of institutions and would therefore predict an effectiveness score close to zero, neo-liberal institutionalists would ideally suggest an effectiveness score close to one. As our findings suggest for the two cases under investigation, aggregate values ranging between 0.31 and 0.39 would be sufficiently far from the ideal positions of both schools of thought. Overall, we conclude that at least some international environmental regimes have substantial effects, but do not yet exploit their full potential.

Future research should systematically link the degree of regime effectiveness (on the aggregate and disaggregate level) with factors explaining its variation across substantive issue areas and time. The perhaps best known general explanation for

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[51] Underdal (fn. 18).

[52] The regime phases constitute the unit of analysis for the statistical evaluation.

[53] All degrees of negative change of regime effectiveness are captured by one scale value ("0") which allows any positive values to dominate the assessment. Ideally, such a scale would be ranging from "-1" to "+1" in order to provide a symmetrical scale. In effect, the present scale takes "negative change" as the reference value and shows to which degree this can be overcome.

regime effects are the 3 C's put forward by Levy et al., namely international regimes acting as

> (i) enhancers of governmental concern,
>
> (ii) enhancers of the contractual environment for mutually profitable agreements, and
>
> (iii) enhancers of national capacity to implement and comply with the rules of international regimes.[54]

While these perspectives point to major explanatory routes to be found in the empirical domain, it remains to be demonstrated in more systematic and comparable form to which *degree* they matter. Young and Levy take a cautious step in this direction, but they „do not claim to have produced a set of empirically-tested generalizations about the sources of regime effectiveness that are valid across a range of issue areas".[55] The most systematic approach to explaining regime effectiveness has been taken by Underdal who focuses on the (i) benignity of the (environmental) problem and (ii) problem-solving capacity.[56] In his findings, Underdal highlights the explanatory power of issue-specific power - understood as a form of entrepreneurial leadership - particularly in the case of malign problems.

Future research may beneficially combine the measurement concept for regime effectiveness advanced in this article with the explanatory factors elaborated above. This would improve our understanding by focusing on broader explanations of the different degrees of effectiveness across regimes (on the aggregate level) and the particular factors influencing country-level effectiveness (on the disaggregated level).

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[54] Marc A. Levy et al., „Improving the Effectiveness of International Environmental Institutions," in Peter M. Haas et al. (fn. 9), 397-426.

[55] Oran R. Young and Marc A. Levy, „The Effectiveness of International Environmental Regimes," in Oran R. Young, ed., *The Effectiveness of International Environmental Regimes: The Causal Connections and Behavioral Mechanisms* (Cambridge, MA: MIT Press, forthcoming). In particular, they refer to the behavioral pathways encompassing regimes as (i) utility maximizers, (ii) enhancers of cooperation, (iii) bestowers of authority, (iv) learning facilitators, (v) role definers, and (vi) agents of internal realignments. Ibid., 4-5.

[56] Underdal (fn. 18).

Appendix: Data Sources and Procedures

A Data Sources

All data sources are summarized in Table 3. In a few cases, further country-specific adjustments had to be made, mainly to take account of changes of territorial borders during the implementation period. A detailed description of those adjustments is available upon request from the authors.

Variables	Data Sources	Remarks
Emissions E_i in base and target years	Barrett and Berge[57]	
Depositions D_i in base years	Barrett and Seland[58]	Barrett and Berge[59] does not contain data on depositions
Conditional pentile (5%) critical loads L_i^*, i.e., pentile of cumulative density functions of all CLs within the country conditional on the level of oxidized nitrogen (oxidized sulfur) depositions in 1993, adjusted by country area	Calculated from aggregated pentile critical loads data (computed on the basis of depositions for 1990), which have been kindly provided by the Co-ordination Centre for Effects (CCE) at the RIVM in Bilthoven (Netherlands) (personal correspondence, 16 January 1997)	The method to transform aggregated pentile critical loads into conditional critical loads is described in Posch.[60] As calculations are performed on a country (rather than grid) basis, the derivation of conditional critical loads requires the assumption that depositions are spread uniformly across the area of individual countries.
Country area	World Bank[61]	Only the European part of the Russian Federation is included.
Transboundary transport coefficients t_{ij} averaged for the years 1985 to 1995	Calculated from deposition budget matrices for SO_2 and NO_x[62]	
Marginal abatement costs $C_i'(E_i)$ of emission reductions relative to the projected pathway of energy use without abatement measures during the implementation period (1980-1993).	RAINS 6.1, Official Energy Pathway 03/1992[63]	Data for 1995 had to be taken as an approximation, because no data for the target years 1993 and 1994 are available

Table 3: Data Sources

[57] Barrett and Berge (fn. 34), 33 and 36.
[58] Kevin Barrett and Øyvind Seland, *European Transboundary Acidifying Air Pollution. EMEP/MSC-W Report 1/95* (Oslo: The Norwegian Meterological Institute, 1995), Appendix E.
[59] Barrett and Berge (fn. 34).
[60] Maximilian Posch, „Critical Loads Exceedances and Ecosystem Protection Percentages,“ in M. Knoflacher, J. Schneider and G. Soja, eds., *Exceedance of Critical Loads and Levels*, Report of a Workshop Held in Vienna, Austria (22-24 November 1995) under the Convention on Long Range Transboundary Air Pollution, 1996.
[61] World Bank, *World Tables 1992*, (Washington, D.C.: World Bank, 1992).
[62] Barrett and Berge (fn. 34).
[63] Alcamo et al. (fn. 35).

B. Emission Reductions in Collective Optimum

The specification of marginal abatement costs as stepwise increasing rather than continuous functions in the RAINS model necessitates a modified procedure to solve equation (5) simultaneously for all countries. First, optimal cooperative emission reductions were calculated for the case of linear damage costs functions. Because this solution does not take into account the decrease of exceedance of critical loads due to emission reductions, the resultant cooperative emission reductions are too high and can be regarded as an *upper* benchmark (see Table 2). Second, when these (maximum) cooperative emission reductions are used to solve the quadratic version of equation (5), the decrease of exceedance of critical loads due to emission reductions of other countries are overestimated, resulting in too low emission reductions in one's own country. Therefore, these (minimum) cooperative emission reductions can be regarded as a *lower* benchmark. Third, the stepwise increasing marginal abatement costs functions within the interval between the lower and upper benchmark have been approximated by linearly increasing functions. The simultaneous equation system now contains only linear equations, which were solved using matrix algebra subject to the constraint that a country's cooperative emission reductions are at least as high as in the non-cooperative solution.

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