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Abstract

This paper pursues two goals: first, to move beyond existing analyses of the effects of general trade openness on national or international environmental policy by developing and testing more specific hypotheses on dyadic trade effects on international policy-outcomes (i.e., problem solving); second, to test these hypotheses based on the best available national and subnational spacial data and new techniques (notably, GIS) for constructing datasets that allow for direct testing of hypotheses on transboundary (instead of national level) outcomes. We develop two hypotheses and test them for transboundary water pollution, an environmental outcome variable reflecting success or failure in international water management: (1) that the intensity of bilateral (dyadic) trade ties has a positive effect on international environmental problem solving; (2) that asymmetry of trade ties in favor of the downstream country is conducive to problem solving in upstream-downstream settings because it balances positional power (upstream) with economic power (downstream). Our dependent variable is water quality, specifically, concentrations of water pollutants from point- (BOD_5) and non-point sources (NO_3^-). The dataset for major international rivers from 1970 - 2003 was constructed with the help of GIS and data from the Global Environmental Monitoring System (GEMS), the European Environmental Agency (EEA), and other sources. Neither the first nor the second hypothesis receives robust empirical support: trade ties do not seem to help in reducing transboundary water pollution, nor do they seem to hinder such efforts. We discuss several possible reasons for this finding and outline options for further research.

Keywords: International cooperation, international trade, water, pollution, environment

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1. Introduction

Research on the effects of trade on international environmental cooperation has thus far focused largely on policy-output (e.g., national environmental regulation, international environmental treaties), rather than policy-outcomes (e.g., environmental quality measured in terms of pollution). One line of research centers on regulatory competition. It holds that trade liberalization tends to push states into a competition in regulatory laxity. It assumes that environmental regulation imposes costs on firms. Firms, in turn, may vote with their feet by relocating to countries with laxer regulation (pollution havens) or threatening governments that they will do so. Politicians experience costs of such corporate behavior (e.g., voter dissatisfaction due to anticipated higher levels of unemployment or reduced tax revenue and thus government services). Since they are anxious to retain firms and capital and attract new investment national politicians tend to be responsive to business demands for regulatory laxity. In the extreme case, this argument predicts a race-to-the-bottom in terms of ever laxer regulatory standards and, as a result, declining environmental quality. In the not so extreme case, it predicts unwillingness of governments to raise regulatory standards, resulting in a regulatory chill (e.g. Daley 1993; Donahue 1994).

Another line of research proposes the opposite. The so-called trading-up argument claims that due to growing linkages among the formerly distinct policy areas of trade and environmental regulation in the global economy international trade provides a catalyst for making domestic environmental regulations more stringent (Vogel 1995, 1999). As national environmental quality thus increases, transboundary problems among any given pair of countries experiencing (separately) growing environmental quality standards will be easier to solve. The traditional version of the trading-up argument holds that, for exogenous reasons, an economically powerful jurisdiction installs stricter environmental standards. This forces producers and their governments in other jurisdictions that have close trade ties with the former jurisdiction to raise their standards as well. This trading-up effect relies on implicit or explicit threats of the former jurisdiction not to let products produced under laxer environmental conditions or products of lower environmental quality into its market. This argument has been refined in at least two ways in recent years. First, due to an increase in public environmental concerns and a decline of public trust in government capacity to solve environmental problems, NGOs reinforce and exploit 'green public preferences' for their campaigns. This generates pull and push effects on producers and weakens their political power to resist more stringent environmental measures (e.g. Radcliffe 1998; Berry 1999; Meins 2003). Second, economic liberalization makes traditional forms of rent seeking harder. Firms are thus experiencing stronger incentives to use environmental performance strategies to enhance their competitive position in domestic and international markets. They then push for public regulation that supports their environmental performance strategies by permitting them to capitalize on proprietary technologies, particular product qualities, advantages in marketing and distribution, or by defining market segments for products (e.g. Hoffman 2000; Reinhardt 2000; World Bank 2000).

Most of the empirical evidence for one or the other claim comes primarily from *qualitative case studies*. By and large, it tends to support the trading-up argument over the regulatory competition argument. Since the 1970s, most advanced industrialized countries have been able to combine liberalization of trade with increasingly stringent environmental standards. Thus, they have at least slowed down or even reversed environmental degradation in various areas, such as air and water quality, energy efficiency, and deforestation (e.g. Levinson 1996; WTO 1999; Wheeler 2000). The same holds for some transboundary environmental problems (e.g., long-range transboundary air pollution). The available evidence also runs counter to the pollution haven hypothesis, which holds that industrialized countries have only become cleaner by shifting polluting industrial activity and waste to poorer countries with laxer environmental regulation (e.g. Revesz 1992; Jaffe, Peterson et al. 1995; Stafford 2000). However, while this trend prevails on average, in some cases, such as climate change, regulatory competition has had obvious chill effects. But such effects appear to be the exception and not the rule, and only in extremely few cases have analysts observed an erosion of existing environmental standards due to international regulatory competition (e.g. Berger and Dore 1996; Vogel and Kagan 2002).

Despite the political prominence of the trade-environment controversy, there is, in comparison to the rather large amount of qualitative case studies, surprisingly little *quantitative* research on the effects of trade on *national* environmental policies. As to the trade-effects on national environmental *policy-output*, Prakash and Potoski (2006), for example, examine the adoption of ISO 14001, a voluntary corporate environmental management standard. They find that trade linkages have a positive effect on adoption rates if a country's most important export markets have adopted this standard. Other authors, e.g. Grossman and Krueger (1995), Antweiler et al. (2001), Ulph (2000), Dean (2002), Copeland and Taylor (1995; 2003), Frankel and Rose (2005), Bernauer and Koubi (2006) and others observe positive effects of trade on national, macroenvironmental performance (*policy-outcomes*) in some areas, such as SO_2 concentrations and deforestation. Moreover, Jaffe, Peterson et al. (1995), Levinson (1996), Wheeler (2000) and others find no substantial evidence for the pollution haven hypothesis.

It is often noted in the aforementioned literature that international trade may also have effects on national environmental quality by influencing states' ability and willingness to solve *international* environmental problems. Yet, very little quantitative research exists on the effects of trade on international environmental policy. Some authors have sought to explain trade effects on *policy-output*. Holzinger, Knill and Sommerer (2006), for example, find no effect of trade on convergence of national environmental policies in a sample of 24 countries in 1970 - 2000. Neumayer (2002a) studies the effect of trade openness on participation in three multilateral environmental agreements. Controlling for income, political freedom and population size, he finds some, albeit weak evidence for possible positive synergies between trade openness and multilateral environmental cooperation.

There is even less quantitative research on the effects of trade on *international* environmental *policy-outcomes*. The only work along these lines for a large number of countries and years has, to our knowledge, been undertaken by Hilary Sigman (2004). She argues that trade may promote environmental cooperation among states in several ways: by providing opportunities for implicit side-payments, thus allowing for linkages between environmental and trade concessions; by providing direct leverage over other countries' production; and by installing a perception of shared goals. Using global data on water quality in international rivers, she estimates the effect of bilateral trade on pollution in rivers that cross international borders. Her results indicate that rivers shared between countries with stronger trade ties are less polluted than rivers shared by countries with weak or no bilateral trade ties. That is, trade seems to promote effective environmental policy coordination. This finding supports the trading-up hypothesis.

We view Sigman's research as a very useful starting point and seek to develop her theoretical arguments further. We also seek to improve the empirical analysis. Theoretically, we differentiate two types of effects of bilateral trade relations: effects emanating from the intensity of trade ties, and effects emanating from asymmetry of trade ties. Empirically, we improve on Sigman's research in two ways. First, we construct two indicators for bilateral trade ties that are closely connected to two distinct theoretical arguments about causal effects of trade on transboundary pollution. While Sigman uses monadic indicators for trade ties we use dyadic indicators. Second, we restrict our dataset to gauging stations providing information on water pollution within a certain radius of the border on an international river. That is, we seek to obtain more accurate data on *transboundary* pollution flows. We also restrict the dataset to clearly identifiable upstream-downstream settings. Such settings are widely viewed in the environmental policy literature as hard cases for international cooperation (Mitchell and Kielbach 2001; Mitchell and Bernauer 2004: 92-93). If trade promotes environmental problem solving in upstream-downstream settings, it should do so also in settings less adverse to cooperation. This restriction also allows for the testing of the hypothesis that trade asymmetry in favor of the downstream country facilitates international environmental problem solving. Sigman's analysis, in contrast, is based on data from all gauging stations along international rivers. Furthermore, we use two important indicators of water quality and two sets of data on water quality (global, European). We are thus able to test the two trade-effects hypotheses for different forms of water pollution (notably, point- and non-point sources), and for the regional (European) and global level.

The empirical findings do not support either hypothesis: trade ties do not seem to help in reducing transboundary water pollution, nor do they seem to hinder international environmental policy in this area. We submit that there are at least four possible reasons for this result: (1) trading-up is less likely in the area of process regulation; (2) upstream-downstream settings make cooperation particularly difficult; (3) the long-term economic effects of trade on pollution (through scale, composition, technique effects) are more important than the short-term political effects; (4) problems with data.

We view our contribution as a first step towards specifying in greater detail the effects of different types of trade relationships on international environmental cooperation, and in using geographic information system (GIS)-based techniques in the construction of datasets to focus the analysis on transboundary policy-outcomes. Whereas most research to date has concentrated on trade-effects on national and international environmental policy-output and national environmental policy–outcomes, the trade-effects on transboundary policy-outcomes remain largely unknown. We submit that understanding the latter effects is crucial because it can tell us whether trade is not only on paper, but also in practice conducive, non-conducive, or irrelevant in solving transboundary environmental problems. Rapidly improving data-handling technologies, such as GIS, and increased availability of environmental and other data for national and subnational levels offer exciting opportunities for pushing forward along these lines.

The following part of the paper develops two theoretical arguments linking trade relationships to state behavior in transboundary environmental problem solving. Part 3 of the paper discusses the dataset and methodology. Part 4 presents the results and part 5 offers some conclusions and ideas for further research.

2. Theory

We begin by deriving from conventional liberal and neo-realist IR theories statements on the effects of bilateral trade on transboundary environmental problem solving. We then consolidate the respective propositions into a general typology of trade relationships and derive two hypotheses.

2.1 Trade Promotes Transboundary Problem Solving

This claim by the liberal school of IR theory originates in two key assumptions in neoclassical trade theory: first, that international trade produces benefits for all participants, even though these benefits may not be distributed equally among the trading partners; second, that trade occurs voluntarily to the extent states can expect to derive benefits from the relationship – if not, states acting rationally would exit the relationship (Gilpin 1987: 172-180; Russett, Starr et al. 2003: 379-381). Liberal IR theory can provide two types of trade-related arguments in favor of environmental policy coordination among states: one emphasizes economic factors (commercial liberalism), the other social factors (social liberalism) (see on this McMillan 1997: 35-40).

Commercial liberalism. One version of this argument is based on the expected-utility model of Polachek (1980) in conflict research. It holds that gains from trade influence rational political leaders' foreign policy behavior, as they seek to maximize social welfare. The rational leader weighs the expected costs of unresolved conflict against lost welfare gains associated with potential trade losses. If the expected welfare losses exceed the costs, she will try to avoid a conflict with her trading partner. Since potential welfare losses tend to increase with growing importance of the trade relationship relative to other trade relationships, more trade will result in less conflict. This model can be applied to transboundary environmental issues instead of militarized disputes (i.e., to environmental cooperation rather than the probability of war).

Trade may foster cooperation among states if political leaders think that the welfare losses associated with problems in their trade relationship due to a problem with a shared natural resource exceed the benefits of leaving the latter problem unresolved. The willingness to solve transboundary environmental problems should thus increase with the economic importance of the trade relationship. Wars are, of course, more likely to disrupt international trade than environmental problems. Nonetheless, one may assume that unresolved environmental problems can affect trade negatively in more indirect ways by disturbing terms of trade or affecting future investments.

In addition to such broad and rather unspecific effects, trade can provide states with opportunities for implicit and explicit side-payments and/or linkages between environmental and trade concessions (e.g. Barrett 2001). Qualitative case-study research has shown that explicit linkages and/or compensations are quite rare in international environmental policy, particularly among advanced industrialized countries (e.g. Keohane and Levy 1996). The latter often prefer issue-isolation strategies over issue-linkage, since the latter tends to increase the complexity of negotiations, raise fairness and legitimacy problems, and may establish precedents that could be used or abused in future negotiations on other issues. However, more indirect forms of side-payments and/or more sequentially and loosely structured issue-linkages are quite common also among advanced industrialized countries. Explicit side-payments and/or issue-linkages are much more common among less-developed countries, notably because they often lack the capacity to solve certain environmental problems. Without side-payments or linkages they would frequently refuse to participate in problem solving in the first place or would accept certain obligations but would not or only insufficiently implement them (Bernauer 1997: 178-179). In other words, depending on the setting in which countries seek to solve transboundary environmental problems, explicit or implicit forms of compensation and/or issue-linkages seem to vary in form and size. Trade relations can offer opportunities for applying various incentive strategies both among industrialized and among industrialized and developing countries.

Social Liberalism. This view holds that trade relations contribute to cooperation also in other than economic ways. It assumes that trade among states stimulates social contacts, which in turn fosters greater understanding and more cooperative behavior (Stein 1993: 249). This argument comes in two varieties. First, the communication approach of Deutsch and others (Deutsch 1953; Deutsch, Burrell et al. 1957). It stipulates that trade, even if pursued only for economic gains, leads to international social contacts that reduce misperceptions, increase understanding, and lead to a convergence of cultures. Applied to the trading-up argument (which is more recent), trade is expected to help NGOs mobilize the public for their goals across borders. Public and NGO pressure on national governments to solve particular environmental problems thus increases, transaction costs are reduced, and perceptions of shared goals are instilled (Neumayer 2002a; Bernauer and Caduff 2004).

The second variety relies on (neo-)functionalist theories (Haas 1958, 1964; Mitrany 1964). It claims that increased contacts among countries necessitate the creation of mechanisms, such as bi- or multilateral agreements, to resolve conflicts that might arise. Cooperation among states in one field often has 'spill-over effects' into other fields. To the extent two policy fields are interlinked, cooperation in one field can positively affect cooperation in the other field. Consequently, growing coordination of trade policies between states can produce growing coordination of environmental policies. Indeed, many qualitative case studies note such spillover effects, since trade may have effects on environmental quality (e.g., through international risk shifting and scale effects), and because national environmental regulations often have direct effects on terms of trade (e.g. Brunetti 1991: 141-149; Killinger and Schmidt 1998).

2.2 Impacts of Trade are Contingent on the Nature of Dependence and Problem Structure

Neorealists share the liberal assumption that trade tends to lead to net absolute benefits but assume that relative rather than absolute gains dominate political decision-making. Since gains from trade affect states' relative power and security in the international system distributional conflict over such gains is presumably pervasive (e.g. Grieco 1990; Snidal 1991; Grieco, Powell et al. 1993; Snidal 1993). Gowa (1994), for example, argues that states trade more with allies to avoid positive security externalities of trade (i.e. growth in national income) in favor of its adversaries. We can infer from these arguments that trade per se will not help in solving transboundary environmental problems. But we can deduce an argument pertaining to the effects of trade-dependency patterns on cooperation in situations characterized by a particular problem structure; namely, that the effectiveness of side-payment and issue-linkage strategies is contingent on the nature of trade dependence and the structure of the environmental problem (see also Barrett 1997; Limão 2002).

We submit that if the environmental problem structure is asymmetric (e.g., pollution of an international river by the upstream country), cooperation is more likely when the environmentally disadvantaged country (e.g., the downstream riparian) can compensate for its inferior positional power by relying on asymmetric trade dependence in its favor to construct issue-linkages or side-payments. That is, the effect of trade is contingent on the distribution of relative gains from trade and the structure of the environmental problem. Solving symmetrical environmental problems may be easier under conditions of symmetrical trade dependence, and asymmetrical problems may require inverse asymmetric trade dependence if trade is to help in solving a given transboundary problem.

2.3 Propositions

Drawing on the aforementioned liberal and neo-realist arguments we can specify two hypotheses for empirical testing. The two schools of thought differ in terms of the specific kind of trade relationship that is required to promote international cooperation. Liberals highlight the intensity of trade ties per se while ignoring distributional issues. The neorealist school directs our attention to contingent effects of trade relationships on international environmental cooperation – the emphasis is on asymmetric trade dependence and variation in environmental problem structure.

Based on Keohane and Nye's (2001: 7-8) definition of types of relationships between states and their conceptualization by Barbieri (2002: 28-41), Figure 1 identifies four types of dyadic trade relationships, focusing on each state's trade share with its partner state.

Figure 1 about here

Quadrants I and IV depict situations in which one state is disproportionately dependent on the other state. Quadrants II and III depict situations of mutual (symmetrical) trade dependence – in the latter quadrant dependence is small (relative independence). The intensity of a trade relationship increases as the two states move away from the origin of the coordinate system and reaches the maximum when each state's trade share with the other is 100 percent. The distance between the dyad and the diagonal line l arising at a 45-degree angle from the origin defines the degree of asymmetry of a trade relationship. The closer a dyads is to this line, the more symmetrical its trade relationship is.

This leads to two dyadic propositions:

(a) The intensity of a bilateral trade relationship has a positive effect on transboundary environmental problem solving among this dyad.

(b) The effect of bilateral trade ties on transboundary environmental problem solving depends on the specific combination of the environmental problem structure and the symmetry/asymmetry of the dyadic trade relationship.

3. Empirical Application, Data, and Statistical Approach

We start by discussing why the focus in this paper is on transboundary water pollution. We then define our variables and describe the dataset and statistical approach.

3.1 Pollution of International Rivers

From the many transboundary environmental problems that exist we select water pollution. First, pollution of freshwater is widely regarded as one of the most important environmental problems worldwide, but is rarely examined in research on environmental policy outcomes. Most forms of water pollution have direct implications for human health, ecosystems, and economies as such (Meybeck, Chapman et al. 1989; Cech 2004: 119-136). International river basins in particular contain a large part of the $9x10^3$ km^3 of freshwater that is available on Earth. Freshwater is, therefore, one of humanity's most vulnerable natural resources: only 0.007% of all water on Earth is consumable freshwater, and it is virtually impossible to substitute (Hauchler, Messner et al. 2000: 300-301).

Second, international rivers are relatively well-defined ecosystems onto which we can map geographical boundaries and identify the environmental problem structure (notably, symmetrical versus asymmetrical transboundary environmental externality flows). In particular, we will select from the many international water problems cases characterized by an upstream-downstream pollution problem. This will allow us to test both hypotheses specified above.

Third, upstream-downstream problems are widely assumed to be particularly difficult to solve (see on this Bernauer 2002: 6-7). In such cases, the upstream country has the positional power to stop polluting the river but often not much interest in doing so, whereas the downstream country does not have the positional power to stop "imports" of pollution but has an interest in having pollution levels reduced. Coasian bargaining in such cases could help in solving the problem. But it is usually complicated because both states tend to refer to equally strong principles in international law in favor of their position: the principle of territorial sovereignty vs. the polluter pays principle (Bernauer 1996a). If international trade relations (either via trade intensity and/or asymmetry effects) are conducive to environmental problem solving in such cases, they should contribute to problem solving in less demanding settings as well. That is, we are exposing the two hypotheses to a particularly hard test (Mitchell and Kielbach 2001; Mitchell and Bernauer 2004: 92-93). This design also allows us to compare our results to those of Sigman (2004), who has not systematically restricted her dataset to upstream-downstream problems.

Fourth, sufficient information is available to construct a dataset with enough observations for carrying out a meaningful quantitative analysis. International rivers are shared by a small and well-defined group of riparian countries that can easily be grouped into dyads.[1] Besides variation in pollution over time we also expect cross-sectional variation within countries because a country may share different rivers with different neighbors.

Fifth, as noted above, very little quantitative research has been carried out to date on the effects of trade on transboundary environmental outcomes (policy-outcomes). To differentiate more clearly various types of trade effects and to address important research design and data problems we opt for an environmental problem on which some (albeit limited) research already exists (notably, the work by Sigman 2004). That is, it seems worthwhile to sharpen the analytical tools and contribute to cumulative knowledge-building in one narrow area before moving to a broader set of dependent variables.

Finally, the quantitative approach adopted here can add to the qualitative case-study work, which is more widespread in this field, but whose findings are harder to generalize than the findings from large-N research.

The two propositions developed above can be specified as follows for the purpose of empirical testing:

(H1) Transboundary water pollution among a country-dyad sharing an international river decreases if the intensity of trade ties among this dyad increases.

(H2) Transboundary water pollution among a country-dyad sharing an international river decreases if trade dependency of the upstream country on the downstream country increases relative to the trade dependence of the downstream country on the upstream country.

3.2 Variables

Water Pollution: Biological Oxygen Demand (BOD_5) and Nitrate (NO_3^-)

One of the biggest gaps in the literature on trade-effects on international environmental cooperation is the lack of studies focusing on policy-outcomes. We thus define our dependent variable in terms of water pollution in international rivers, and biological oxygen demand (BOD_5) and nitrate (NO_3^-) in particular. These indicators can be regarded as proxies for success (or failure) in reducing or avoiding transboundary water pollution. We have chosen these two measures for several reasons.

Numerous national and international authorities, such as the UN, the European Environmental Agency (EEA), or the US Environmental Protection Agency (EPA) use BOD_5 and NO_3^- to describe water quality. Moreover, many countries around the world as well as international and supranational organizations (e.g., the WHO and EEA) have established

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[1] There are more than 260 major international river basins worldwide. They cover around 45% of the Earth's land surface. The majority of these international river basins are shared by two riparian states (around 68%). 19 international river basins have five or more riparian states and only four basins (Danube, Niger, Nile and Congo) have more than 9 riparian states (Wolf, Natharius et al. 1999).

standards (limits) for both indicators (Meybeck, Chapman et al. 1989: 22-28, 79-91, 126-127; United Nations Environment Programme 1991: 15, 18; Europäische Umweltagentur 2004).

The two water-quality parameters are relatively easy (though not trivial) to measure with standard procedures. Hence the consistency in data quality across countries and time is acceptable, and both indicators are available for a relatively large number of countries and over relatively long periods of time.

Both BOD_5 and NO_3^- can travel rather far downstream. This is important because we are focusing on transboundary pollution externalities. Other pollutants, such as pathogens that have more direct effects on human health, usually do not travel more than a few kilometers downstream. Transboundary externalities are thus less important in those cases.

Both indicators can be attributed to general forms of anthropogenic pollution (notably, sewage in the case of BOD_5 and extensive use of synthetic fertilizers in agriculture in the case of NO_3^-). This attribution is possible because these pollutants have low background values and low levels of natural variation, so that neither heterogeneity in local industrial activity nor heterogeneity in geological or environmental attributes has a strong influence on the two indicators.

Emissions of both pollutants can be reduced if governments decide to do so. BOD_5 is related to the oxygen (O_2) regime of a river and measures the proportion of organic pollution on oxygen depletion. Although every river contains some organic load (natural background values are between 1 and 2 mg O_2/l), the main source of organic pollution is the discharge of untreated sewage. Reducing the amount of sewage discharge into a river and/or installing sewage treatment plants can curtail organic pollution (United Nations Environment Programme 1991: 17; European Environmental Agency 2003a). But doing so is costly. NO_3^- belongs to the group of nutrients that are essential substances for plants, animals, bacteria, and microorganisms. They provide energy to these organisms and thus permit growth. To some extent NO_3^- is also produced by non-anthropogenic sources (natural background values are around 0.3 mg N/l). Nonetheless, it is produced primarily through artificial processes and is found in most common fertilizers used in agriculture. Applied in proper amounts, nitrates are very beneficial. But excessive use in agriculture may lead to high concentrations in ground and surface water, which causes eutrophication and has detrimental health effects notably on children (e.g., the so-called 'Blue-Baby-Syndrome') (Meybeck, Chapman et al. 1989: 107-120, 126-127; United Nations Environment Programme 1991: 18; European Environmental Agency 2003a; Cech 2004: 127, 131-133). Reducing the use of fertilizers containing high amounts of nitrate, using natural or alternative artificial fertilizers, changing agricultural production methods, and increasing efficiency in agricultural production can curtail NO_3^- pollution. But technical know-how and technology are less widely available and more expensive than in the case of sewage treatment equipment.

We use these two indicators also to account for the two main categories of anthropogenic pollution sources: point- and non-point sources (Cech 2004: 113-118). This distinction is important. Pollution from point sources is easier to identify and quantify than pollution from non-point sources. It is thus widely assumed that pollution from point sources is easier to control by governments than pollution from non-point sources.

Our data for BOD_5 and NO_3^- comes from two sources and allows us to test the two hypotheses at the global and the European level. For the global level our data consists of annual and triennial observations for 1979-1996 from a maximum of 51 measurement stations located along international rivers within 100 km of the respective international border. This data was collected through standardized procedures under the Global Environmental Monitoring System (GEMS), which is sponsored by the WHO and UNEP (see appendix for data sources). For the European level, our data consists of annual observations for 1970-2005 from a maximum of 38 stations located along international rivers within 5 km of the respective international border. This data was collected through standardized procedures by the EEA, an agency of the EU.

Following common practice in other studies on the determinants of pollution (e.g. Grossman and Kruger 1995; Antweiler, Copeland et al. 2001; Sigman 2004; Bernauer and Koubi 2006) we use the logarithmic transformation of the mean pollution concentrations. The measurement unit is mg O_2/l and mg N/l respectively.

Bilateral Trade Relations: Intensity and Asymmetry

We focus on two aspects of bilateral trade relations, as pointed out in the two hypotheses to be tested. In doing so we draw on a measurement concept proposed by Barbieri (2002: 57-62; 2003). *Intensity* measures the importance of a bilateral trade relationship relative to other trade relationships. *Asymmetry* measures bilateral inequity of trade dependence between the two partners. We start by constructing a national measure of trade dependence for any given dyadic relationship.

$$\text{Trade Dependence}_{i,t} = \frac{\text{Dyadic Trade}_{ij,t}}{\text{Total Trade}_{i,t}} = \frac{\text{Imports}_{ij,t} + \text{Exports}_{ij,t}}{\sum_{k=1}^{N}(\text{Imports}_{ik,t} + \text{Exports}_{ik,t})} \qquad (1)$$

where N is the number of trade partners of state i, t is the time, and j denotes the state with regard to which trade dependence of state i is measured. If a state has many different trading partners and does not assign much importance to any particular trading partner, the value of equation 1 will be low relative to any other state. If a state conducts most of his trade with only one country, his trade dependence vis-à-vis that country is high and equation 1 produces a high value. The indicator ranges from 0 and 1. 0 indicates no trade between i and j, and 1 indicates total trade dependence of state i on state j.

To compute a dyadic measure of intensity we need some method for averaging the national dependence scores. We use the geometric mean rather than the arithmetic mean, since the former is less outlier sensitive and produces zero as soon as one of the two trade dependence values equals zero. We consider both effects to be theoretically desirable since highly unequal trade dependence of states should not lead to higher values in intensity than more equal trade dependence among pairs of states. We thus define the intensity of a bilateral trade relationship between states i and j at time t as

$$\text{Intensity}_{ij,t} = \sqrt{\text{Trade Dependence}_{i,t} * \text{Trade Dependence}_{j,t}} \qquad (2)$$

Equation 2 produces values ranging from 0 to 1. Higher values indicate more intensive trade relationships. We expect a negative relationship between intensity and pollution levels as measured at stations located near or on the border of an international river.

To test the second proposition we also use a directional measure for asymmetry in the trade relationship between the upstream country i and the downstream country j at time t. This asymmetry is defined as

$$\text{Asymmetry}_{ij,t} = \text{Trade Dependence}_{i,t} - \text{Trade Dependence}_{j,t} \qquad (3)$$

Equation 3 produces values ranging from -1 to 1. Positive values indicate higher trade dependence of the upstream country on the downstream country; negative values indicate higher trade dependence of the downstream on the upstream country. We expect a negative relationship between asymmetry and pollution levels.

All trade data was taken from version 4.1 of the expanded trade and GDP dataset by Gleditsch (2002).

Economic Variables: Scale Effect, Composition Effect, Technique Effect, Openness

Studies on the economy-environment relationship have most often used income and sometimes also trade openness as surrogates for several underlying economic factors that individually influence environmental quality (e.g. Grossman and Kruger 1993). Recent theoretical and empirical studies (in particular Antweiler, Copeland et al. 2001; Copeland and Taylor 2003) have decomposed economic impacts on the environment into scale, composition, and technique effects. We adopt this approach by including several pollutant specific economic control variables.

The scale effect of an economic activity is defined as the intensity with which the activity is pursued. Since the pollutants we examine do not primarily occur naturally or accidentally, we assume that the larger the scale of economic activity related to the pollutants is, the higher the level of pollution is likely to be. The hydrological literature shows that discharge of untreated sewage is the main reason for high levels of BOD_5 and results in oxygen depletion in a river. Since sewage stems primarily from human excrements and biological waste we measure the scale of sewage production by *population per square kilometer (population density) in a gauging station's catchment area per year*. To that end we use data on flow direction from the US Geologic Survey's (USGS) Global Hydro1K database as well as global population grids (adjusted for UN totals) for the years 1990, 1995, 2000, and 2005[2] provided by the Center for International Earth Science Information Network (CIESIN). We import this data into a geographic information system (GIS) model to calculate this variable, using the flow accumulation function in the ArcGIS 9.0 software. For all other years in our sample the values were intra- or extrapolated based on the four years for which data is available. To a large extent high levels of nitrate in a river result from extensive use of synthetic fertilizers in agricultural production. We measure the intensity of agricultural production by the *amount (metric tons) of fertilizers consumed per square kilometer of irrigated and arable crops land per year* in the upstream country. For both measurements we expect a positive relationship between pollution levels and the intensity of upstream activity, controlling for all other related effects in their production.

The composition of economic activity influences pollution levels because different sectors of the economy affect the environment differently. As to NO_3^- pollution of water, agriculture is more pollution intensive than either industry or services. We measure composition in this regard with the *percentage of irrigated and arable crops per square kilometer in a gauging stations' catchment area*. This indicator is constructed with the flow accumulation function in ArcGIS 9.0 on the basis of a GIS model using data on flow direction from the USGS Global Hydro1k database and the USGS Global land cover data for 1993. Because no consistent, high resolution land cover data is freely available over time this variable does not vary over time. Nevertheless, we expect a positive effect of this composition indicator on pollution. We do not compute a composition indicator with respect to BOD_5 because sewage 'production' resulting from human excrements and biological waste cannot be altered.

A large body of literature on the environmental Kuznets curve holds that at lower income levels people are more concerned about food, shelter, and other material needs. They will be less concerned about environmental quality and are less likely to have the capacity to afford costly environmental clean-up or pollution control measures. As income levels rise, people usually demand higher levels of environmental quality and can afford higher environmental clean-up costs. We thus expect a negative relationship between per capita income and pollution levels. We proxy this income (or technique) effect by including a *moving three-year average of lagged real income (GDP per capita in thousands of US-Dollars*) of the upstream country.

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[2] The values for 2005 are estimates by CIESIN.

Finally, we include an indicator for general trade openness of each pair of riparian states. Countries open to international trade in general are also more likely to trade extensively with their neighbors. If a country's general trade openness also affects pollution levels, as several previous studies on trade and the environment suggest (e.g. Copeland and Taylor 1995; Lehr and Maxwell 2000; Antweiler, Copeland et al. 2001; Unteroberdoerster 2001; Dean 2002; Copeland and Taylor 2003), not controlling for this effect could bias the coefficients of the bilateral trade indicators. Similar to the trade intensity variable, we measure a country pair's trade openness with the *geometric mean of both countries' ratio of the sum of exports and imports to real GDP per year*. The sign of this relationship is theoretically ambiguous because of offsetting forces (positive effect of trade on income and on the scale of production, composition effect) and may differ depending on the pollutant.

Political Variables: Political System, EU Membership

Previous research has shown that democratic governments are likely to choose lower pollution levels than autocratic regimes (e.g. McGuire and Olson 1996; Deacon 1999; Barrett and Graddy 2000; Neumayer 2002b; Bernauer and Koubi 2006). It has also shown that democracies are, economically, more open and have more extensive trade relations with other democracies than with autocracies (e.g. Bliss and Russett 1998; Morrow, Siverson et al. 1998; Mansfield, Milner et al. 2000). We use the polity2 variable from the POLITY IV dataset to control for these effects (Marshall and Jaggers 2004). We transform this variable to an eleven-point scale (0 – 10). We use the *geometric mean of both countries' transformed polity2 scores for each year* and expect a negative effect of democracy on pollution levels.

Moreover, we include a dummy variable for each pair of riparian states. Its value is 1 if both states are *members of the EU* and 0 if not. EU member states are democratic market economies that operate in an integrated, EU-wide market that fosters economic openness and extensive trade relations among its members. Formally starting with the adoption of the Single European Act (SEA) in 1986, the EU has also had the authority to issue and enforce binding environmental standards, including standards for water quality (Hildebrand 2002: 27-31; Knill 2003: 24-34). We expect a negative relationship between joint EU membership and water pollution.

Other Variables: Average River Flow, Deoxygenating Rate

River characteristics at gauging stations, e.g., water temperature and flow rates, are unlikely to be strongly correlated with our two indicators for bilateral trade relations. But their influence on pollution levels has been noted in the hydrological literature (e.g. Bowie, Mills et al. 1985; Meybeck, Chapman et al. 1989; Cech 2004). We therefore include two variables from the GEMS and EEA datasets to obtain more accurate estimates.

Since both dependent variables in our analysis measure the concentration of pollutants in a specific amount of water, *average river flow*[3] at each gauging station should be controlled. River flow determines the dilution rate and thus the effect of waste input on in-stream pollution concentrations. We expect a negative effect of river flow on pollution.

BOD_5 levels indicate the amount of oxygen consumed by bacterial activity within five days, keeping everything else constant. Since biochemical processes run faster at higher temperatures, which results in higher oxygen consumption through bacterial activity and growth, water temperature at the gauging station has to be controlled for. To control for the speed of natural attenuation we use the time rate of exponential decay of BOD_5 (known as the *deoxygenation rate k*). We calculate this value from GEMS and EEA data on water

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[3] For gauging stations where no annual or triennial mean data was provided, we used averages for longer time-periods provided by GEMS and EEA station lists. Where flow data was still missing we entered 0 and constructed a dummy variable that takes the value 1 when flow data was missing and 0 if not.

temperature[4], using a nonlinear function from the hydrological literature (Bowie, Mills et al. 1985: 139). We expect a negative effect of the deoxygenation rate on pollution.

Time trend

We include a *time variable* in our regression analysis to control for general trends in income, economic structure of countries, and trade liberalization that are related to a trend towards lower pollution observed during the sample period.

3.3 Construction of Datasets

The two datasets for the analysis were constructed in four steps. First, all stations located on national rivers were dropped from the GEMS and EEA station lists because they are irrelevant to our study. Second, in the global dataset, stations on international rivers that are located more than 100 kilometers away from the border were dropped from the sample. The same was done for stations in the European dataset that are located more than 5 kilometers away from the border. Through this selection we restrict the analysis to the effects of trade on the level of *transboundary* pollution. Third, we dropped all stations where, according to the river flow, no obvious upstream and downstream countries could be identified. We thus restrict the analysis to upstream-downstream problems and control for problem structure. In those few cases where water quality of an international river was measured simultaneously in the border area by the upstream and downstream country we dropped the station with data coverage for the shorter time-period and/or fewer observations to ascertain cross-sectional independence in the sample. Fourth, we added up- and downstream countries according to the revisited list of independent states (Gleditsch and Ward 1999) and assigned our variables to the cases.

Construction of the dataset for the European level was unproblematic – we use annual means for both pollutants based on data provided by the EEA. It is more complicated at the global level. There we combined annual and triennial means based on data provided by the GEMS. To save observations that would be lost due to the inclusion of a one-year lagged dependent variable on the explanatory side of our statistical model (see below), we copied (where possible) the three-year lagged triennial means and pasted them one year before the next observation. To ensure consistency, we used triennial means for all variables if triennial means were used for the dependent variable and annual means otherwise. Both datasets have an unbalanced panel structure.

In summary, our unit of analysis is the gauging station that is located in an upstream-downstream setting and measures pollution levels as they cross an international boundary. One such dataset includes gauging stations in Europe, the other includes stations from around the world. Countries and gauging stations included in the analysis are listed in the appendix.

3.4 Statistical Approach

The empirical analysis is based on two types of statistical models. They allow us to exploit the panel-structure of the data and also study cross-sectional variation. In addition, they help in assessing the robustness of results since first-order serial autocorrelation turns out to be difficult to handle with the panel dataset.

The statistical model in the panel-analysis takes the following form:

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[4] Several stations did not report annual or triennial water temperature. Following Grossman and Kruger (1995: 362) we estimate water temperature for each station based on the maximum number of available observations and the decimal geographic coordinates (x/y) of a station and its elevation (GEMS estimation: n=157, $R^2 = 0.6$; EEA estimation: n=96, $R^2 = 0.5$).

$$\begin{aligned}\text{Pollutant}_{ijt} \;=\;& \beta_0 \;+\; \beta_1 * \{\text{bilateral trade variables}\} \;+\; \beta_2 * \{\text{economic variables}\} \\ &+\; \beta_3 * \{\text{political variables}\} \;+\; \beta_4 * \{\text{other variables}\} \;+\; \beta_5 * \text{year} \;+\; e_{sijt}\end{aligned}$$

where Pollutant is the natural logarithm of the mean concentration of BOD_5 or NO_3^- at station s near the border between countries i and j in time-period t. $\beta_k = 1,2,3,4,5$ denote the vectors of the coefficients and e_{sijt} is the idiosyncratic error.

In addition to the variables listed above we include a dummy variable for the river location of the country that reports the respective pollution concentration to GEMS or the EEA, and we interact the bilateral trade variables with the dummies for the river location of the reporting countries.[5] We do so because countries participating in GEMS and EEA monitoring program are free to participate and are unrestricted in choosing monitoring locations; hence they may choose such locations strategically. Upstream countries may have an incentive to report cleaner water selectively and downstream countries may have the opposite incentive.

We use a log-level functional form for the estimation of equations. Exceptions to the log-level specification are the variables measuring scale and composition effects and river flow; these are included by their natural logarithm since they are likely to have multiplicative effects.

The estimates of the panel models are based on the Beck and Katz (1995) approach. We did not use the more common fixed or random effects approach for the following reasons. First, none of the latter two methods permits the weighting of observations in the standardized procedures of Stata 8.2; yet, this seems necessary in our case (see below). Second, random effects estimations assume that the observations were randomly drawn from a larger population. Because countries cannot be forced, neither by the GEMS nor by the EEA, to provide data, using random effects would lead to inefficient and biased coefficients (Wooldridge 2003: 469-473). Third, fixed effects estimation relies on the procedure of first differences. As a result, time-consistent factors or factors changing rarely over time are not estimated efficiently. Indeed, some of our control variables, e.g., land cover characteristics, upstream location of a gauging station, or the political structure of a country, do not or only marginally change over time (Wooldridge 2003: 461-467).

First-order serial autocorrelation is dealt with by including the one-time period lagged dependent variable on the explanatory side (Beck and Katz 1995: 645). Problems of panel heteroskedasticity and contemporary autocorrelation are addressed by using panel corrected standard errors (PCSE) (Beck and Katz 1995: 645). Our models are estimated with weighted least squares, using the number of measurements as weights. The reason is that our pollution level measurements are means of multiple measurements; differences in the number of measurements may thus cause heteroskedastic errors. Finally, since the panel datasets are highly unbalanced we compute the covariance for each element in the covariance matrix. We do so for all available observations that are common in at least two panels contributing to the covariance (pair wise case selection) rather than only in the observations that are available for all panels (case wise case selection) (Stata Corporation 2003: 190-211).

The statistical model for the cross-sectional analysis has the same form and specifications (e.g., interaction terms for river location of reporting country and bilateral trade variables, log-level functional form, weighting observations by number of measurements) as the model for the panel data, but uses arithmetic means of all times series variables. As a result, the cross-sectional models also differ from the panel-regression models in that they do not need a coefficient capturing the time trend.

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[5] That is, we allow different intercepts and slopes depending on whether the upstream or downstream country has taken and reported the pollution measurements.

4. Results

We first report the descriptive statistics for the global and European datasets and then discuss the results of regressions of BOD_5 and NO_3^- on the explanatory variables.

4.1 Descriptive Statistics

At least three conclusions can be drawn from Tables 1a and 1b. First, independent of geographic scale and pollutant, all variables vary much more cross-sectionally than longitudinally. Second, virtually all variables and notably our two main independent variables are characterized by higher standard deviations at the global than at the European level. Third, as to the temporal distribution of observations, the global data for both pollutants is concentrated in the 1980s, with only a few observations in the late 1990s; the European data is heavily concentrated in the second half of the 1990s, with only few observations in the 1970s and 1980s. Significant effects of bilateral trade relationships on water quality in international rivers are, therefore, more likely to be found in cross-sectional analysis at the global level.

Table 1a about here

Table 1b about here

Table 2a reports the correlation coefficients for BOD_5 and the explanatory variables for both datasets. Table 2b reports the equivalent statistics for NO_3^-.

Table 2a about here

Table 2b about here

Tables 2a and 2b show that the correlation coefficients for trade intensity and water pollution have positive (except for NO_3^- at the global level) instead of the expected negative signs – empirically, more intense bilateral trade seems to be associated with more transboundary pollution. The coefficients for water pollution and trade asymmetry (in favor of the downstream country), on the other hand, have the anticipated negative sign (except for NO_3^- at the global level). Moreover, trade intensity is highly, positively correlated with the lagged triennial mean GDP/cap. of the upstream countries at the global and joint EU membership at the European level. This indicates that dyads with intense trade relationships are often characterized by joint EU membership and high GDP per capita of upstream countries. This finding suggests that it may be difficult, empirically, to distinguish economic and political effects of trade in terms of trade intensity due to problems of multicollinearity. Judging from the correlation coefficients this problem does not exist for trade asymmetry.

Several control variables, such as GDP per capita of upstream countries, joint EU membership, political structure, and trade openness are highly correlated. That is, EU member states tend to be rich, democratic market-economies that are heavily engaged in international trade. Tables 2a and 2b also show that the number of observations on which the coefficients are based is moderate, ranging from 87 to 207 at the global and 227 to 280 at the European level. The number of observations for NO_3^- at the global level is quite small.

4.2 Regression Analysis

We start by discussing the results of panel-regressions of BOD_5 on the explanatory variables at the global and European level and also report the equivalent results for NO_3^-. We then present the results of cross-sectional regressions before comparing the findings across geographic scales, pollutants, and statistical approaches.

4.2.1 Panel Regression Analysis

Table 3 reports the results of panel regressions for BOD_5 at the global and European level. It shows that neither trade intensity nor asymmetry (in favor of the downstream country) has a significant effect on BOD_5, neither at the global nor the European level. Trade asymmetry has a significant effect on water pollution at the global level if pollution is measured and reported by downstream countries. Yet, the coefficient for the effect of trade asymmetry on pollution as measured and reported by upstream countries is far from statistical significance (p-value = 89.2%). This indicates that the effect is not robust and independent of reporting countries' geographical position. Most control variables have the expected signs, but their effects are, generally, rather weak and often insignificant. It is noteworthy, however, that there is a significant, negative time trend in all but one estimation (in estimation 3 its p-value is 10,2%). That is, transboundary water pollution decreases over time. High joint trade openness has, in all but one estimation (estimation 4 its p-value is 9.8%), no net effect on transboundary water pollution. This indicates that an increase in general trade openness over time has led neither to more, nor to less pollution. The explanatory power of the regression equations is high (between 85% and 87%). This is due primarily to the inclusion of a one-time period lagged dependent variable that is by far the strongest determinant of current BOD_5 levels in international rivers.

Table 3 about here

Comparing the results for the global level with those for the European level produces at least three noteworthy findings. First, the effect of the lagged dependent variable is considerably stronger in the global dataset than in the European one, whereas the time effect in the European dataset is slightly stronger than in the global one. This indicates that, globally, water pollution is highly path dependent and is decreasing only slowly, whereas in Europe water pollution is somewhat less path dependent and is decreasing somewhat faster. Second, population density has no significant effect on BOD_5 in the global dataset, but has a significant effect in the European dataset. This may be due to differences in data coverage over time. Since consistent, spatially referenced population data is only available for 1990 - 2005, intra- and extrapolated estimates are certainly more precise for the 1990s than for the 1980s. This may explain the difference in size and statistical significance across geographic scales. Moreover, these differences and rather low coefficients may also reflect downward bias due to measurement errors, given the insufficiently fine resolution and hydrological correction of the Hydro 1k flow direction grid. Data problems may also explain the third of the aforementioned differences across the datasets. The effect of the deoxygenation rate k has the expected sign and reaches statistical significance globally, but has no significant effect at the European level. More missing water temperature data and therefore a higher amount of estimated values in the European dataset than in the global one might explain this finding.

Table 4 about here

Table 4 shows the results of panel regressions for NO_3^-. Again, it does not offer significant support for the trade intensity and asymmetry hypotheses. Estimation 3 indicates that with increasing trade intensity transboundary NO_3^- pollution also increases. One reason for this finding could be the high partial correlation between trade intensity and joint EU-membership (r = 0.83), which leads to problems of multicollinearity. The control variables behave largely as expected, but their effects on pollution levels are, again, rather small and often insignificant. The main exception is the effect of the percentage of irrigated and arable cropland in a gauging station's catchment area. This variable has a significant, positive effect on transboundary NO_3^- concentrations in all estimations. Its quantitative effect, however, varies substantially across the datasets. It is almost four times stronger at the global than at the

European level. The explanatory power of the equations is high, which is again due primarily to the inclusion of the one-time period lagged dependent variable.

Comparing the results for NO_3^- across the two datasets is somewhat difficult because the global results are only based on 60 observations. With this caveat in mind, we observe that the effect of the lagged dependent variable is stronger in the European than the global dataset. The net effect of trade openness is significant and strong at the European level, but small, negative, and insignificant for the global dataset. This indicates that transboundary NO_3^- pollution is highly path dependent and has increased with growing trade openness at the European level, and that it is less path dependent and largely unaffected by trade openness at the global level. These differences might stem from variation across countries in agricultural production patterns at the global and European level. In contrast to BOD_5, transboundary NO_3^- pollution is particularly severe among highly developed countries (and is getting worse as their trade openness increases). One of the reasons is likely to be that the majority of countries in the European dataset are highly developed countries that tend to use more fertilizers in agricultural production.

The results for the European dataset support the widely shared view that water pollution from point sources (BOD_5) is easier to tackle than water pollution from non-point sources (NO_3^-). The one-time period lagged dependent variable has a stronger effect and the time trend effect is weaker and statistically less significant for NO_3^- than for BOD_5. Moreover, the technique (income) effect on BOD_5 is twice the size of the technique effect on NO_3^-.

We exposed the above findings to extensive tests in order to assess their robustness. We started by altering estimation specifications: notably, we included a two-time period lagged dependent variable in addition to the one-time period lagged dependent variable, estimated a common and panel specific first-order serial autocorrelation process, and included country pair fixed effects. Moreover, we altered the specification of the statistical model by replacing the dyadic indicators for trade openness, political structure, and EU-membership with monadic indicators for each riparian state. We then re-estimated all eight equations, thus taking into account separately all changes in estimation and model specifications in different combinations. With one exception the results did not change significantly. The exception is that the positive effect of trade intensity on NO_3^- at the European level became insignificant in these other model specifications. This finding casts doubt on the robustness of the trade intensity effect on NO_3^-. We also examined whether some outliers might have driven our results. No single or small group of outliers could be identified.

4.2.2 Cross-Sectional Regression Analysis

In this section we report the results of a cross-sectional analysis, even though all regressions are based on less than 30 observations. The reasons are as follows. First, the descriptive statistics (Tables 1a and 1b) show that all variables vary much more cross-sectionally than longitudinally. Consequently, bilateral trade relationships might have an effect on transboundary pollution across observations that may not be observed in panel regression analysis where between and within variation is combined. Second, the panel regressions show that transboundary water pollution is heavily path and time dependent – most of the observed variation in the dependent variable is explained by the one-time period lagged dependent variable and the time trend. By running cross-sectional regressions we rule out these two variables and can therefore test more clearly the effect of trade intensity and asymmetry on transboundary water pollution.

Table 5

Table 5 presents the results for BOD_5 at the European and global levels. Neither trade intensity nor asymmetry has a significant negative effect on transboundary pollution. Estimation 4 (trade intensity at the European level) even produces a statistically significant (although very weak), positive effect of trade intensity on pollution. Most control variables have the expected sign. One noteworthy exception is the coefficient for the deoxygenation rate k, which is positive in all estimations, but is significant only for the European dataset. However, this finding may well be a statistical artifact due to the small number of observations and the fact that rivers in the southern hemisphere have both higher water temperatures and higher pollution levels.

Two findings are noteworthy in comparing the global with the European level. First, the model fit is better for the European than the global scale. Second, population density in a river catchment area, GDP per capita in the upstream country, and river characteristics contribute to explaining differences in BOD_5 in Europe, but not at the global level. The reasons for these findings may be twofold. The unit homogeneity is likely to be higher at the European than at the global level, which reduces the risk of omitted variable bias. Data quality is likely to be better at the European than the global level.

Table 6 about here

Table 6 shows the results for NO_3^-. Again, the trade intensity and asymmetry hypotheses do not receive empirical support. Most control variables have the expected sign, but are mostly insignificant. As for BOD_5, the explanatory variables perform better at the European than the global level. The percentage of irrigated and arable cropland in a gauging station's catchment area and joint trade openness help in explaining cross-sectional variation at the European but not the global level. The reasons are likely to be the same as those mentioned for BOD_5.

5. Conclusion

In this paper we have undertaken first steps towards filling an important gap in the trade-environment literature, namely, the lack of quantitative studies on the effects of trade on *international* environmental *policy-outcomes*. Specifically, the paper has pursued two goals: first, to move beyond existing analyses of the effects of general trade openness on environmental policy by developing and testing more specific hypotheses on dyadic trade effects on international environmental policy outcomes (i.e., problem solving); second, to test these hypotheses based on the best available national and subnational spacial data and new techniques (notably, GIS) for constructing datasets that allow for direct testing of hypotheses on transboundary (instead of national level) outcomes.

We have tested two propositions derived from liberal and neorealist IR theory: (a) that the intensity of bilateral trade ties has a positive effect on transboundary environmental problem solving; (b) that transboundary environmental problems disproportionately affecting one of the two states are easier to solve when the dyadic trade relationship is in favor of the environmentally disadvantaged state. The empirical focus was on transboundary water pollution in major international rivers in 1970-2003. The analysis was based on data for point source pollution (BOD_5) and non-point source pollution (NO_3^-) at the global and European level. The data was obtained from the GEMS, the EEA, and other sources. The dataset was constructed with the help of GIS.

The analysis does *not* provide robust empirical support for the two propositions. Neither the intensity of bilateral trade ties nor the asymmetry of bilateral trade relationships in favor of the downstream country has a robust, significant effect on the ability of riparians to solve transboundary water pollution problems. Our empirical findings do, therefore, not support earlier results by Sigman (2004). We submit that this difference is primarily due to the fact that we use two measures for bilateral trade ties that are more tightly linked to the theoretical argument than general trade openness, and that we expose the two propositions to harder empirical testing. In addition, our results suggest that empirical findings of some other studies in favor of the trading-up hypothesis may not apply to *transboundary* environmental problem solving – those studies focus on national-level policy-output or policy-outcomes (e.g. Antweiler, Copeland et al. 2001; Prakash and Potoski 2006) or international policy-output (e.g. Neumayer 2002a).

There are at least four possible reasons why we do not observe a significant effect of trade on transboundary water pollution: (1) trading-up is less likely in the area of process regulation; (2) upstream-downstream settings make cooperation particularly difficult; (3) the long-term economic effects of trade on pollution (through scale, composition, technique effects) are more important than the short-term political effects; (4) problems with data.

(1) Though some empirical studies (e.g. Prakash and Potoski 2006) find trading-up effects also for process regulation, the trading-up hypothesis assumes that positive effects of trade on environmental protection levels will be most pronounced in the area of product standards (examples include emission standards for cars and GM food). Reducing water pollution, however, is clearly a matter of process regulation. Under existing global and most regional trade rules, market-entry barriers based on environmental process regulation are, with some rare exceptions, prohibited. We do not know of any explicit import-restrictions based on criteria of water pollution associated with production processes.

(2) Upstream-downstream water pollution is usually characterized by a deadlock-game structure, which is often hard to overcome because it requires a Coasian solution (i.e., side-payments) that may imply high transaction costs (e.g. Keohane and Levy 1996; Bernauer 1996a, 2002). That is, high trade intensity and trade asymmetry in favor of the downstream country seem to be insufficient for overcoming upstream-downstream problems. That is, trade ties may, in principle, offer opportunities for issue-linkages and side-payments, but such opportunities may be harder to exploit than is assumed in our two trade-effects hypotheses. Our finding that transboundary water pollution is highly path-dependent (very little variation over time) indeed demonstrates that international cooperation in this area is very slow and difficult. As shown in this paper, most progress has been made in Europe and for point-sources of pollution. Our results receive indirect confirmation by studies on trade effects on greenhouse gas emissions. Frankel and Rose (2005), for example, find no effect of general trade openness on CO_2 emissions. CO_2 emissions, even though measured at the national level, are per se a transboundary pollutant – emissions anywhere have global effects. It is, theoretically, well established that such global public bads are similarly hard to reduce through international cooperation than unidirectional transboundary externalities (as in the case of upstream-downstream water pollution).

(3) It is empirically quite well established that some forms of pollution follow a Kuznets-curve pattern and also decline with growing trade-openness. However, it might be the case that these effects materialize primarily at the national level and extend to transboundary environmental issues only with some delay – the assumption is that cleaner countries are also less likely to “export” pollution to neighboring countries. Such effects may be difficult to capture in a quantitative empirical analysis. That is, even in cases where we observe declining transboundary water pollution accompanied by substantial international policy-output designed to reduce pollution (e.g. see the Rhine case in Bernauer and Moser 1996b), actual pollution reduction may be due primarily to broader economic trends at national levels that then spill over across boundaries, rather than to explicit international environmental cooperation (on problems of measuring international regime effectiveness, see Helm and Sprinz 2000).

(4) We have used the best available data on transboundary water pollution. However, there are obviously substantial gaps in the data (the same problem affects virtually all other empirical studies on trade-environment linkages). Besides incomplete data coverage there could also be problems of strategic data reporting – that is, data exists but it could be biased by the interests of governments collecting and reporting the data. Moreover, global GIS models are still plagued by inaccurate data representation, and there are substantial multicollinearity problems in the two datasets. In other words, it seems rather difficult to capture political effects of trade on transboundary water quality management when data quality is less than optimal and pollution levels are also affected by all sorts of direct and indirect economic effects.

Further research should focus on at least three areas. First, empirical testing should be extended to additional forms of transboundary pollution to the extent data is available. The most obvious candidate is long-range transboundary air pollution, for which reasonably good data exists at least for Europe and North America. Even though it is quite well established that some forms of air pollution have developed along similar pathways as some forms of water pollution, it remains to be seen whether trade-environment linkages are weak or non-significant not only in two important areas of water pollution, as shown in this paper, but also in other environmental areas. In particular, it will be interesting to find out whether trade effects are more substantial in environmental problem areas that are more conducive to cooperation (i.e., do not have an upstream-downstream or global public goods character).

Second, theoretical propositions and empirical testing should be more closely connected, primarily by targeting empirical testing more specifically at observable implications along causal pathways leading from trade relations to environmental problem solving. For example, the liberal argument claims that trade helps in solving transboundary environmental problems by increasing social contacts across national borders, which in turn also enhances NGO's opportunities for influencing similar groups and/or citizens in the other country. This, in turn, can produce stronger pro-environment pressure on governments in both countries. One way of testing this argument could be to estimate models that contain an interaction term between trade intensity and the strength of environmental NGOs.

Third, more sophisticated empirical models are needed to take particular data properties more fully into account and exploit the panel structure of the data more effectively. Assuming that states engage in strategically motivated location of monitoring stations and data reporting, particularly when pollution levels have reached politically critical thresholds, we may have underestimated the real effects of trade relationships on international environmental problem solving. If this assumption is empirically relevant, statistical models that can cope with the problem of nonrandom sample selection (e.g., selection models) and model the selection of monitoring sites might be able to establish significant and robust effects of certain bilateral trade relationships on transboundary environmental problem solving. However, this task is very difficult for at least two reasons. First, we do not have a theory telling us when different states choose to report what kinds of data on environmental quality, and what factors lead them to locate monitoring stations in particular places. Second, the number of potential dyads along international rivers and potential monitoring locations along those rivers is very large. In addition, we do not have much data on characteristics of unmonitored places along national borders in international river basins.

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Figures and Tables

Figure 1 (Adapted from Barbieri (2002: 40)):

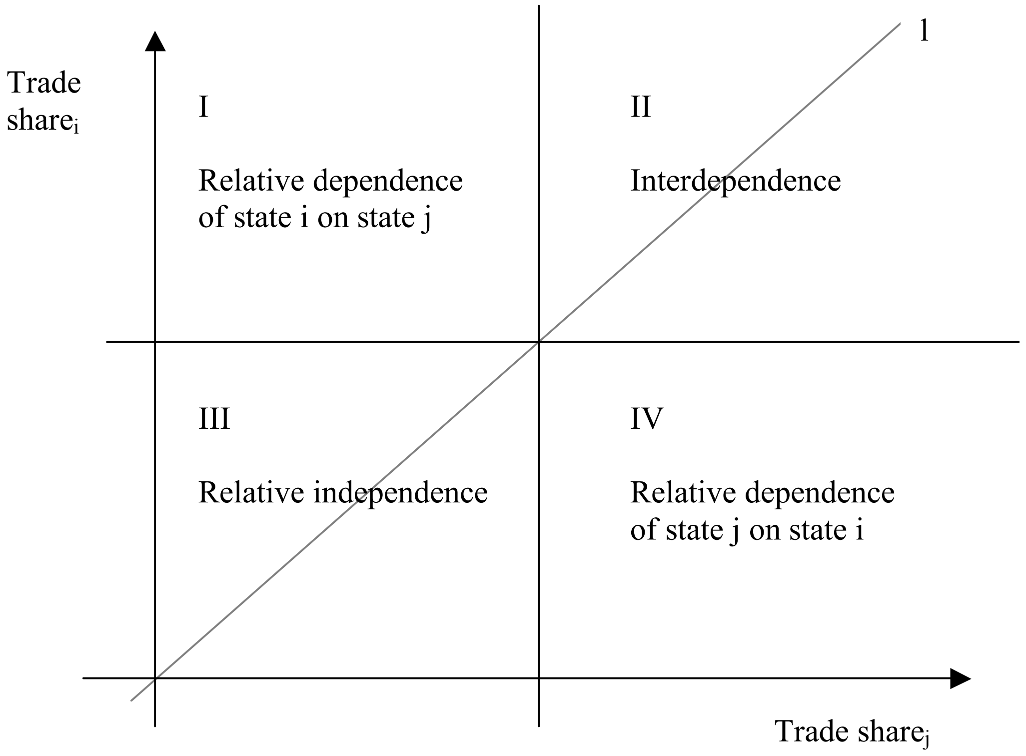

Table 1a: Descriptive statistics for BOD_5 at the global and European level

Variable		**Mean**	**Std. Dev.**	**Min**	**Max**	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Obs**
Global dataset (GEMS)							*Regional dataset (EEA)*				
ln(BOD_5)	overall	1.095	0.585	-1.088	2.367	N = 246	1.102	0.657	-1.609	2.625	N = 310
	between		0.548	-0.312	2.348	n = 34		0.533	-0.173	2.079	n = 29
	within		0.322	0.087	2.347	T-bar = 7.235		0.329	-0.334	2.268	T-bar = 10.690
intensity	overall	0.086	0.061	0	0.264	N = 243	0.071	0.047	0	0.154	N = 252
	between		0.058	0	0.207	n = 32		0.041	0.012	0.143	n = 26
	within		0.012	0.036	0.144	T-bar = 7.594		0.011	0.027	0.133	T-bar = 9.692
asymmetry	overall	-0.004	0.24	-0.71	0.91	N = 243	-0.021	0.090	-0.361	0.121	N = 252
	between		0.21	-0.61	0.64	n = 32		0.089	-0.346	0.103	n = 26
	within		0.07	-0.44	0.27	T-bar = 7.594		0.014	-0.157	0.011	T-bar = 9.692
ln(popdensity)	overall	7.341	1.281	4.059	9.166	N = 215	7.189	0.821	5.278	8.290	N = 310
	between		1.186	4.131	8.888	n = 34		0.728	5.335	8.290	n = 29
	within		0.071	7.055	7.694	T-bar = 6.324		0.071	6.818	7.556	T-bar = 10.690
GDP	overall	12.473	7.888	1.138	30.941	N = 240	15.864	6.388	4.350	25.870	N = 249
	between		7.850	1.266	24.376	n = 29		7.137	4.350	25.040	n = 28
	within		1.542	4.973	19.038	T-bar = 8.276		1.851	10.144	20.727	T-bar = 8.893
openess	overall	0.369	0.280	0.024	1.163	N = 243	0.409	0.217	0.039	0.895	N = 252
	between		0.249	0.029	0.790	n = 32		0.185	0.120	0.757	n = 26
	within		0.089	0.171	0.750	T-bar = 7.594		0.142	0.031	0.821	T-bar = 9.692
polity	overall	7.644	3.069	0.707	10	N = 243	9.379	1.235	2.937	10	N = 310
	between		3.095	1.5	10	n = 32		1.196	5	10	n = 29
	within		1.228	4.559	14.699	T-bar = 7.594		0.824	4.079	12.406	T-bar = 10.690
EU	overall	0.486	0.499	0	1	N = 243	0.358	0.480	0	1	N = 310
	between		0.485	0	1	n = 32		0.380	0	1	n = 29
	within		0.074	-0.403	1.041	T-bar = 7.594		0.145	-0.392	0.644	T-bar = 10.690
ln(flow)	overall	4.703	3.625	0	10.820	N = 215	4.530	2.003	0	8.713	N = 310
	between		3.068	0	10.820	n = 34		2.483	0	8.713	n = 29
	within		0.560	2.354	9.147	T-bar = 6.324		0.074	4.078	4.897	T-bar = 10.690
flowmiss	overall	0.276	0.448	0	1	N = 215	0.058	0.234	0	1	N = 310
	between		0.382	0	1	n = 34		0.351	0	1	n = 29
	within		0.081	-0.647	0.943	T-bar = 7.235		0	0.058	0.058	T-bar = 10.690
k	overall	0.328	0.100	0.199	0.646	N = 215	0.249	0.027	0.175	0.303	N = 310
	between		0.106	0.214	0.603	n = 34		0.026	0.175	0.297	n = 29
	within		0.025	0.227	0.428	T-bar = 6.324		0.006	0.221	0.275	T-bar = 10.690
Stations: 31, Rivers: 25, Country pairs: 26, Mean of time period: 1986.5							Stations: 26, Rivers: 21, Country pairs: 24, Mean of time period: 1992.6				

Table 1b: Descriptive statistics for NO_3^- at the global and European level

Variable		**Mean**	**Std. Dev.**	**Min**	**Max**	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Obs**
Global dataset (GEMS)							*Regional dataset (EEA)*				
ln(NO_3^-)	overall	-0.084	1.567	-6.908	2.814	N = 128	0.432	0.869	-3.507	1.792	N = 398
	between		1.410	-3.441	1.788	n = 23		0.757	-1.246	1.588	n = 35
	within		0.687	-3.551	2.363	T-bar = 5.565		0.323	-2.901	2.343	T-bar = 11.371
intensity	overall	0.097	0.105	0	0.398	N = 130	0.080	0.049	0	0.158	N = 323
	between		0.090	0	0.375	n = 23		0.044	0.012	0.144	n = 32
	within		0.009	0.057	0.138	T-bar = 5.652		0.012	0.006	0.143	T-bar = 10.094
asymmetry	overall	-0.068	0.205	-0.692	0.194	N = 130	-0.019	0.118	-0.361	0.344	N = 323
	between		0.188	-0.620	0.144	n = 23		0.112	-0.342	0.306	n = 32
	within		0.015	-0.141	-0.019	T-bar = 5.652		0.015	-0.155	0.020	T-bar = 10.094
ln(fertilizer)	overall	13.115	2.199	6.476	15.582	N = 117	7.378	0.732	4.742	8.445	N = 355
	between		2.113	8.878	15.422	n = 21		0.739	5.716	8.180	n = 30
	within		0.595	10.713	14.566	T-bar = 5.571		0.238	6.059	8.552	T-bar = 11.833
ln(landuse)	overall	-1.165	1.378	-7.434	-0.042	N = 106	3.823	0.740	1.651	4.562	N = 398
	between		1.735	-7.434	-0.042	n = 24		0.696	1.651	4.562	n = 35
	within		0	-1.165	-1.165	T-bar = 4.417		0	3.823	3.823	T-bar = 11.371
GDP	overall	10.364	8.319	1.138	27.108	N = 129	15.466	6.297	4.350	25.870	N = 323
	between		8.448	1.152	23.576	n = 24		6.921	4.350	25.040	n = 33
	within		1.296	6.875	13.959	T-bar = 5.375		1.746	9.750	20.330	T-bar = 9.788
openess	overall	0.262	0.274	0.008	1.163	N = 130	0.401	0.208	0.065	1.284	N = 323
	between		0.315	0.026	0.979	n = 23		0.227	0.150	1.284	n = 32
	within		0.078	0.039	0.617	T-bar = 5.652		0.134	0.023	0.813	T-bar = 10.094
polity	overall	6.817	3.389	0.707	10	N = 126	9.167	1.699	2.806	10	N = 396
	between		3.238	1.732	10	n = 23		1.757	2.806	10	n = 35
	within		1.443	3.109	10.902	T-bar = 5.478		0.778	4.564	12.910	T-bar = 11.314
EU	overall	0.277	0.449	0	1	N = 130	0.392	0.489	0	1	N = 398
	between		0.487	0	1	n = 23		0.416	0	1	n = 35
	within		0	0.277	0.277	T-bar = 5.652		0.147	-0.418	0.983	T-bar = 11.371
ln(flow)	overall	6.720	2.761	0	10.820	N = 106	4.833	2.124	0	8.713	N = 398
	between		3.307	0	10.820	n = 24		2.501	0	8.713	n = 35
	within		0.863	4.707	12.520	T-bar = 4.417		0.088	4.371	5.419	T-bar = 11.371
flowmiss	overall	0.085	0.280	0	1	N = 106	0.063	0.243	0	1	N = 398
	between		0.378	0	1	n = 24		0.355	0	1	n = 35
	within		0.120	-0.665	0.335	T-bar = 4.417		0	0.063	0.063	T-bar = 11.371
Stations: 23, Rivers: 20, Country pairs: 18, Mean time period: 1986.8							Stations: 30, Rivers: 24, Country pairs: 30, Mean time period: 1992.7				

Table 2a: Partial correlations for BOD$_5$ at the global and European level

Global dataset (GEMS); Obs= 207											
	ln(BOD$_5$)	intensity	asymmetry	ln(popdensity)	GDP	openess	polity	EU	ln(flow)	flowmiss	k
ln(BOD$_5$)	1.00										
intensity	0.231	1.00									
asymmetry	-0.254	-0.379	1.00								
ln(popdensity)	0.172	-0.056	-0.053	1.00							
GDP	0.302	**0.690**	-0.401	-0.062	1.00						
openess	0.309	0.394	0.006	0.207	**0.706**	1.00					
polity	0.283	0.454	-0.239	0.257	**0.708**	**0.706**	1.00				
EU	0.357	0.454	-0.022	0.224	0.648	**0.788**	**0.765**	1.00			
ln(flow)	-0.465	-0.393	0.088	-0.037	-0.611	-0.707	-0.645	-0.774	1.00		
flowmiss	0.341	0.249	-0.024	0.047	0.390	0.604	0.515	0.672	-0.879	1.0	
k	-0.275	-0.315	-0.215	0.027	-0.507	-0.585	-0.447	-0.510	0.539	-0.326	1.00
Regional dataset (EEA); Obs= 227											
	ln(BOD$_5$)	intensity	asymmetry	ln(popdensity)	GDP	openess	polity	EU	ln(flow)	flowmiss	k
ln(BOD$_5$)	1.00										
intensity	0.400	1.00									
asymmetry	-0.263	-0.319	1.00								
ln(popdensity)	0.574	0.314	-0.340	1.00							
GDP	-0.334	0.285	-0.176	0.151	1.00						
openess	-0.219	0.186	-0.390	0.091	**0.727**	1.00					
polity	-0.139	0.311	-0.096	0.089	0.523	0.433	1.00				
EU	0.429	**0.934**	-0.374	0.241	0.157	0.202	0.252	1.00			
ln(flow)	-0.386	-0.445	-0.020	0.138	0.159	0.016	-0.194	-0.494	1.00		
flowmiss	0.117	-0.128	0.094	-0.100	-0.280	-0.162	0.038	-0.125	-0.475	1.00	
k	0.557	0.416	-0.289	0.691	0.062	0.024	-0.063	0.434	-0.053	-0.046	1.00

Table 2b: Partial correlations for NO_3^- at the global and European level

Global dataset (GEMS); Obs= 87											
	ln(NO_3^-)	intensity	asymmetry	ln(fertilizer)	ln(landuse)	GDP	openess	polity	EU	ln(flow)	flowmiss
ln(NO_3^-)	1.00										
intensity	-0.027	1.00									
asymmetry	0.181	**-0.772**	1.00								
ln(fertilizer)	0.583	0.473	-0.366	1.00							
ln(landuse)	0.582	-0.106	0.312	0.465	1.00						
GDP	0.155	**0.866**	-0.677	0.662	-0.016	1.00					
openess	0.548	0.325	-0.009	0.676	0.402	0.638	1.00				
polity	0.474	0.592	-0.407	**0.834**	0.315	**0.716**	0.653	1.00			
EU	0.628	0.245	0.129	0.671	0.445	0.522	**0.835**	0.598	1.00		
ln(flow)	-0.077	0.097	-0.053	0.025	-0.156	-0.129	-0.313	-0.060	-0.236	1.0	
flowmiss	-0.039	-0.156	0.144	-0.280	0.097	-0.040	0.092	-0.136	0.060	-0.730	1.00
Regional dataset (EEA); Obs= 280											
	ln(NO_3^-)	intensity	asymmetry	ln(fertilizer)	ln(landuse)	GDP	openess	polity	EU	ln(flow)	flowmiss
ln(NO_3^-)	1.00										
intensity	0.417	1.00									
asymmetry	-0.364	-0.335	1.00								
ln(fertilizer)	0.213	0.534	-0.294	1.00							
ln(landuse)	0.505	0.426	-0.088	0.375	1.00						
GDP	0.025	0.381	-0.172	**0.750**	0.162	1.00					
openess	0.223	0.268	-0.268	0.364	-0.029	**0.702**	1.00				
polity	0.091	0.439	-0.076	0.212	0.246	0.554	0.389	1.00			
EU	0.406	**0.834**	-0.168	0.392	0.369	0.246	0.267	0.284	1.00		
ln(flow)	0.050	-0.021	-0.174	0.260	-0.035	0.270	0.062	-0.096	-0.232	1.00	
flowmiss	-0.113	-0.149	0.076	-0.341	-0.024	-0.271	-0.104	0.048	-0.102	-0.512	1.00

Table 3: Panel regressions for BOD_5 at the global and European level

Variable	**Estimation 1** **Global (intensity)**	**Estimation 2** **Global (asymmetry)**	**Estimation 3** **European (intensity)**	**Estimation 4** **European (asymmetry)**
Ln(BOD_5)$_{t-1}$	0.799*** (0.073)	0.763*** 0.073	0.547*** (0.097)	0.580*** (0.095)
Measurement by downstream country	-0.177 (0.260)	-0.052 (0.062)	0.102 (0.067)	-0.042 (0.044)
Intensity of trade relationship if downstream measurement	0.734 (1.116)		-0.681 (1.806)	
Intensity of trade relationship if upstream measurement	-0.320 (0.873)		1.981 (1.621)	
Asymmetry of trade relationship if downstream measurement		**-0.519*** (0.160)**		0.018 (0.226)
Asymmetry of trade relationship if upstream measurement		-0.026 (0.194)		0.515 (0.759)
Ln(population density)	0.024 (0.025)	-0.010 (0.019)	0.132*** (0.046)	0.144*** (0.046)
Lagged three year average GDP per capita	-0.009 (0.006)	-0.017*** (0.004)	0.207 (0.194)	-0.028*** (0.007)
Trade openness of a dyad	0.040 (0.173)	0.217 (0.138)	0.207 (0.194)	0.345* (0.208)
Political structure of a dyad	0.011 (0.010)	0.004 (0.011)	0.001 (0.016)	0.010 (0.016)
Joint EU membership of a dyad	-0.049 (0.052)	0.021 (0.067)	-0.072 (0.151)	-0.012 (0.077)
Ln(flow)	-0.031 (0.021)	-0.022 (0.022	-0.032* (0.018)	-0.042** (0.020)
Dummy variable for missing flow values	-0.127 (0.152)	-0.134 (0.148)	0.162 (0.180)	0.066 (0.199)
Deoxygenation rate k	-0.606* (0.336)	-1.411*** (0.432)	2.156 (1.566)	2.635 (1.658)
Time trend	-0.008* (0.004)	-0.008** (0.003)	-0.008 (0.005)	-0.011** (0.004)
Constant	16.538*	16.571**	14.614	21.37**
Number of observations (N)	158	158	201	201
Overall R^2	0.853***	0.862***	0.872***	0.868***

Dependent variable: Ln(BOD_5). The coefficients are non-standardized regression coefficients. The PCSE-standard errors are in parentheses. *** = $p<0.01$; ** = $p<0.05$; * = $p<0.1$; the starts associated with R^2 denote the level of statistical significance of the estimated model.

Table 4: Panel regressions for NO_3^- at the global and European level

Variable	**Estimation 1**	**Estimation 2**	**Estimation 3**	**Estimation 4**
	Global (intensity)	**Global (asymmetry)**	**European (intensity)**	**European (asymmetry)**
$Ln(NO_3^-)_{t-1}$	0.646*** (0.103)	0.625*** (0.108)	0.800*** (0.087)	0.808*** (0.086)
Measurement by downstream country	-0.051 (0.450)	-0.546 (1.016)	-0.015 (0.088)	-0.011 (0.065)
Intensity of trade relationship if downstream measurement	2.634 (5.203)		**1.285**** **(0.581)**	
Intensity of trade relationship if upstream measurement	-1.199 (2.459)		**1.318**** **(0.618)**	
Asymmetry of trade relationship if downstream measurement		-0.605 (0.557)		-0.007 (0.124)
Asymmetry of trade relationship if downstream measurement		2.390 (2.713)		-0.081 (0.224)
Ln(fertilizer)	-0.099 (0.119)	-0.125 (0.111)	0.068 (0.066)	0.106 (0.075)
Ln(landuse)	0.269*** (0.090)	0.264*** (0.088)	0.090* (0.046)	0.080** (0.041)
Lagged three year average GDP per capita	0.003 (0.034)	0.012 (0.025)	-0.028* (0.015)	-0.031* (0.017)
Trade openness of a dyad	-0.0637 (0.286)	0.051 (0.254)	0.469*** (0.167)	0.449 (0.174)
Political structure of a dyad	0.124** (0.055)	0.132 (0.057)	0.012 (0.036)	0.029 (0.043
Joint EU membership of a dyad	-0.124 (0.605)	0.035 (0.351)	-0.047 (0.033)	0.034 (0.037)
Ln(flow)	-0.007 (0.024)	-0.005 (0.025)	0.0004 (0.008)	0.003 (0.009)
Dummy variable for missing flow values	-0.0373 (0.236)	-0.054 (0.266)	-0.252 (0.281)	-0.227 (0.274)
Time trend	-0.003 (0.013)	-0.010 (0.012)	0.001 (0.004)	0.001 (0.004)
Constant	6.707	21.15	-2.730	-2.776
Number of observations (N)	**60**	**60**	253	253
Overall R^2	0.935***	0.937***	0.888***	0.887***

Dependent variable: $Ln(NO_3^-)$ The coefficients are non-standardized regression coefficients. The PCSE-standard errors are in parentheses. *** = $p<0.01$; ** = $p<0.05$; * = $p<0.1$; the starts associated with R^2 denote the level of statistical significance of the estimated model.

Table 5: Cross sectional regressions for BOD_5 at the global and European level

Variable	**Estimation 1** **Global (intensity)**	**Estimation 2** **Global (asymmetry)**	**Estimation 3** **European (intensity)**	**Estimation 4** **European (asymmetry)**
Measurement by downstream country	-0.119 (1.248)	-0.443 (0.502)	-0.015 (0.206)	-0.035 (0.129)
Intensity of trade relationship if downstream measurement	2.051 (5.799)		**8.543*** **(4.832)**	
Intensity of trade relationship if upstream measurement	5.759 (6.556)		**10.288**** **(3.887)**	
Asymmetry of trade relationship if downstream measurement		0.437 (1.523)		-1.697 (1.077)
Asymmetry of trade relationship if upstream measurement		-0.666 (2.821)		2.046 (1.922)
Ln(population density)	0.206 (0.187)	0.246 (0.176)	0.123*** (0.032)	0.143** (0.050)
Lagged three year average GDP per capita	-0.004 (0.045)	0.022 (0.062)	-0.071*** (0.015)	-0.056*** (0.016)
Trade openness of a dyad	0.713 (1.282)	0.736 (1.346)	0.673 (0.576)	0.689 (0.718)
Political structure of a dyad	-0.122 (0.118)	-0.140 (0.138)	0.026 (0.082)	0.018 (0.103)
Joint EU membership of a dyad	-0.358 (0.672)	-0.432 (0.914)	-0.622 (0.370)	-0.013 (0.208)
Ln(flow)	-0.313* (0.148)	-0.311 (0.202)	-0.060 (0.047)	-0.157** (0.069)
Dummy variable for missing flow values	-0.964 (1.050)	-0.835 (1.252)	-0.326 (0.354)	-0.749 (0.043)
Deoxygenation rate k	2.292 (2.608)	3.071 (3.980)	8.068*** (2.648)	12.522*** (3.000)
Constant	1.535	1.316	-1.208	-1.668
Number of observations (N)	**28**	**28**	**26**	**26**
R^2	**0.572**	**0.541**	0.881***	0.856***
Adj. R^2	**0.278**	**0.225**	0.788***	0.746***

Dependent variable: Ln(BOD_5). The coefficients are non-standardized regression coefficients. The normal standard errors are in parentheses. *** = $p<0.01$; ** = $p<0.05$; * = $p<0.1$; the starts associated with R^2 denote the level of statistical significance of the estimated model.

Table 6: Panel regressions for NO_3^- at the global and European level

Variable	**Estimation 1**	**Estimation 2**	**Estimation 3**	**Estimation 4**
	Global (intensity)	**Global (asymmetry)**	**European (intensity)**	**European (asymmetry)**
Measurement by downstream country	-0.711 (1.546)	-1.284 (1.001)	0.232 (0.439)	-0.377 (0.298)
Intensity of trade relationship if downstream measurement	-7.314 (12.516)		-4.206 (7.898)	
Intensity of trade relationship if upstream measurement	**-9.049*** **(4.379)**		**9.279*** **(4.883)**	
Asymmetry of trade relationship if downstream measurement		-2.428 (1.579)		-0.362 (1.838)
Asymmetry of trade relationship if downstream measurement		2.674 (3.065)		-1.313 (2.080)
Ln(fertilizer)	0.327 (0.263)	0.211 (0.269)	-1.062 (0.648)	-0.625 (0.905)
Ln(landuse)	0.192 (0.238)	0.178 (0.242)	0.948*** (0.248)	0.945** (0.339)
Lagged three year average GDP per capita	0.067 (0.126)	-0.061 (0.078)	0.016 (0.086)	-0.039 (0.125)
Trade openness of a dyad	-1.724 (1.067)	-0.797 (1.206)	3.064** (1.134)	3.693*** (1.222)
Political structure of a dyad	0.047 (0.242)	0.166 (0.228)	-0.272 (0.251)	-0.157 (0.328)
Joint EU membership of a dyad	1.185 (0.973)	1.017 (0.926)	-0.666* (0.367)	-0.255 (0.302)
Ln(flow)	-0.115 (0.154)	-0.206 (0.135)	-0.089 (0.063)	-0.070 (0.091)
Dummy variable for missing flow values	-1.076 (1.277)	-1.682 (1.220)	-1.593** (0.606)	-1.432* (0.711)
Constant	-2.865	-0.537	5.896	2.573
Number of observations (N)	**21**	**21**	**26**	**26**
R^2	0.919***	0.918***	0.826***	0.762***
Adj. R^2	0.819***	0.819***	0.689***	0.574***

Dependent variable: Ln(NO_3^-) The coefficients are non-standardized regression coefficients. The normal standard errors are in parentheses. *** = p<0.01; ** = p<0.05; * = p<0.1; the starts associated with R^2 denote the level of statistical significance of the estimated model.

Rivers and dyads included in the panel regressions

BOD_5 global dataset

River	Dyad(s)
Brahmaputra	India-Bangladesh
Colorado	USA-Mexico
Danube	Germany-Austria Czechoslovakia-Hungary
Duoro	Spain-Portugal
Elbe	Democratic Republic of Germany-Germany
Escaut	France-Belgium
Ganges	India-Bangladesh
Ghent	Belgium-Netherlands
Irtysh	Kazakhstan-Russia
Maas	France-Belgium
Oder	Czech Republic-Poland
Parana	Paraguay-Argentina
Ravi	India-Pakistan
Rhein	France-Germany Germany-Netherlands
Rhone	Switzerland-France
Sambre	France-Belgium
Scheldt	Belgium-Netherlands
Selenga	Mongolia-Russia
Sure	Belgium-Luxembourg Luxembourg-Germany
Surma	India-Bangladesh
Tajo	Spain-Portugal

BOD_5 European dataset

River	Dyad(s)
Arda	Bulgaria-Greece
Danube	Germany-Austria Austria-Slovakia Czechoslovakia-Hungary
Daugava	Belarus-Latvia
Drau	Austria-Slovenia
Escaut	France-Belgium
Garonne	Spain-France
Inn	Switzerland-Austria
Mosel	France-Germany
Mur	Austria-Slovenia
Nemunas	Belarus-Lithuania
Oder	Czech Republic-Poland
Rhone	Switzerland-France
Sambre	France-Belgium
Struma	Bulgaria-Greece
Tisa	Hungary-Yugoslavia Hungary-Serbia
Vardar	Yugoslavia-Greece Macedonia-Greece
Venta	Latvia-Lithuania

NO_3^- global dataset

River	Dyad(s)	River	Dyad(s)
Bassac	Cambodia-Vietnam	Niger	Guinea-Mali
Brahmaputra	India-Bangladesh	Oder	Czech Republic-Poland
Colorado	USA-Mexico	Parana	Paraguay-Argentina
Danube	Germany-Austria	Ravi	India-Pakistan
Ganges	India-Bangladesh	Rhein	France-Germany Germany-Netherlands
Maas	Belgium-Netherlands	St. Lawrence	USA-Canada
Mekong	Cambodia-Vietnam		

NO_3^- European dataset

River	Dyad(s)	River	Dyad(s)
Arda	Bulgaria-Greece	Nemunas	Belarus-Lithuania
Danube	Germany-Austria Austria-Slovakia Slovakia-Hungary	Oder	Czech Republic-Poland
Daugava	Belarus-Latvia	Rhein	France-Germany Germany-Netherlands
Drau	Austria-Slovenia	Rhone	Switzerland-France
Elbe	Czech Republic-Germany	Sambre	France-Belgium
Escaut	France-Belgium	Struma	Bulgaria-Greece
Garonne	Spain-France	Tisa	Hungary-Yugoslavia Hungary-Serbia
Inn	Switzerland-Austria	Vardar	Yugoslavia-Greece Macedonia-Greece
Mosel	France-Germany	Venta	Latvia-Lithuania
Mur	Austria-Slovenia		

Data Sources

BOD_5	Global Environmental Monitoring System (GEMS) Water (http://www.gemswater.org/publications/index-e.html)
	European Environmental Agency (EEA) Waterbase – Rivers Version 5 (http://dataservice.eea.eu.int/dataservice/metadetails.asp?id=758)
NO_3^-	Global Environmental Monitoring System (GEMS) Water (http://www.gemswater.org/publications/index-e.html)
	European Environmental Agency (EEA) Waterbase – Rivers Version 5 (http://dataservice.eea.eu.int/dataservice/metadetails.asp?id=758)
Trade and GDP data	Expanded Trade and GDP Data (http://weber.ucsd.edu/~kgledits/exptradegdp.html)
Fertilizer consumption	Food and Agriculture Organization (FAO) of the United Nations (http://faostat.fao.org)
Population density	Gridded Population of the World (http://sedac.ciesin.columbia.edu/gpw)
Land cover data	U.S. Geological Survey (USGS) Global Land Cover Characterization (http:// edcsns17.cr.usgs.gov/glcc/glcc.html)
Political structure	Polity IV Dataset (http://www.cidcm.umd.edu/inscr/polity)
EU-membership	European Union (http://europa.eu.int)
River flow	Global Environmental Monitoring System (GEMS) Water (http://www.gemswater.org/publications/index-e.html)
	European Environmental Agency (EEA) Waterbase – Water Quantity Version 2 (http://dataservice.eea.eu.int/dataservice/metadetails.asp?id=752)
Water temperature	Global Environmental Monitoring System (GEMS) Water (http://www.gemswater.org/publications/index-e.html)