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THE POLLUTION HAVEN HYPOTHESIS

Does Trade Promote Environmental Coordination?: Pollution in International Rivers

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Abstract

This paper examines whether trade relationships facilitate resolution of international environmental spillovers. Trade might promote cooperation by providing opportunities for implicit side payments, allowing linkage between environmental and trade concessions, providing direct leverage over other countries' production, or instilling a perception of shared goals. Using data from the UN's Global Environmental Monitoring System (GEMS) on water quality in international rivers, the paper examines the influence of bilateral trade on pollution in rivers that cross international borders. It reports evidence of lower water pollution in rivers shared between countries with more extensive trade. Improved coordination from expanded trade may thus represent a benefit to weigh against the environmental costs of the pollution havens effect.

KEYWORDS: Environment, Transboundary Pollution, Water Quality

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International trade may help resolve transboundary environmental disputes for several reasons. First, trade provides opportunities for implicit side payments if explicit side payments are politically difficult. Second, trade may allow agreements with "linkage" between environmental and trade concessions, providing economic threats to support bargaining over environmental objectives (Limão, 2002). Third, integrated economies allow countries direct leverage over each other's production, for example through the pollution content tariffs suggested by Copeland (1996). Finally, economic interactions may instill a perception of shared goals that helps resolve disputes in other arenas (Neumayer, 2002).

This paper is the first to study the empirical relationship between bilateral trade and transboundary pollution specifically between the trading partners. The paper examines whether the intensity of bilateral trade affects pollution in rivers shared by the two countries.

Rivers offer several advantages as a context in which to examine the effect of bilateral trade relationships. First, different rivers each represent a distinct resource problem and thus a separate observation; regional or global pollution problems, such as acid rain or greenhouse gases, have only a few outcomes at any one time. Second, rivers are shared by a small and well-defined group of countries, making it possible to choose a limited number of bilateral trade values relevant to the resource. Third, a country may share different rivers with different neighbors, giving rise to cross-sectional variation even within countries. Finally, trade will only play a role for pollution problems with some hope of coordination. The small number of parties make Coasean bargaining more feasible for rivers than for regional and global pollution problems involving large numbers of countries.

A number of treaties address transboundary freshwater agreements.[1] However, I focus on the effects of trade on revealed pollution levels, rather than participation in explicit agreements. Explicit agreements may be public relations exercises rather than binding environmental policy. Several earlier studies suggest that environmental treaties do not constrain behavior (Conte Grande, 1997; Murdoch, Sandler, and Sargent, 1997; Congleton, 1995). In addition, countries may reach accommodations that they do not formalize with a treaty.

The United Nations' Global Environmental Monitoring System (GEMS) provides panel data on pollution levels at 247 river monitoring stations around the world, 72 of which are shared between two countries. I matched data from GEMS to data from Statistics Canada (1998) on bilateral trade between the countries sharing the river. Other explanatory variables include country characteristics (such as income, political rights, and general openness to trade), population upstream from the station (calculated using a Geographic Information System (GIS)), and other river characteristics that may affect pollution. The data are analyzed using country and monitoring-station fixed effects to address unobserved heterogeneity. Robustness analyses vary the measures of the intensity of bilateral trade and address the potential endogeneity of trade, using a gravity model of trade. I study biochem-

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[1] Hamner and Wolf (1998) describe 6 (4%) of 145 treaties as principally addressing pollution. However, a current web version of their database now lists 100 agreements with some bearing on water quality out a total of over 400 (Wolf, 2004).

ical oxygen demand (BOD), a common form of pollution for which earlier research shows evidence of free riding by upstream countries (Sigman, 2002).

The results support the hypothesis that trade facilitates environmental cooperation. When country effects are included in the equation, trade intensity at upstream and downstream stations reduces pollution levels. The results are robust to varying the definition of trade intensity and accounting for the endogeneity of trade. Station fixed effects equations do not yield effects of trade, but this may reflect the limitations of using time-series variation to identify the effect of trade on environmental relationships.

The outline of the paper is as follows. Section 1 discusses the possible relationship between shared environmental quality and the level of trade between the environmental partners. Section 2 describes the water pollution data, trade data and other variables assembled for the project. Section 3 presents estimated equations, using fixed effects and a variety of measures of trade intensity. Section 4 briefly concludes.

1. Agreements, trade, and transboundary pollution

International trade between neighbors may affect transboundary pollution because of its effects on policy coordination or the effects of trade on overall pollution levels. This section provides more discussion of these two types of effects.

1.1 Coordination

Trade may facilitate coordination of policies for four related reasons. First, environmental agreements for rivers are likely to require side payments from the downstream countries to the upstream polluting countries (Mäler, 1990).[2] Governments may find it politically difficult to make substantial direct payments to other governments or to pollution sources in other countries; these payments seem to validate a right of upstream countries to pollute that downstream countries may perceive as unfair. Greater potential gains from trade and more extensive economic contacts may facilitate implicit side payments. These side payments may take the form not only of trade preferences, but also other rewards, such as government purchasing contracts, that will be available if the countries' economies are well integrated.

Whether direct side payments are politically difficult is an empirical question. Direct side payments for pollution reduction do sometimes occur. For example, a convention concerning chlorine pollution of the Rhine involved direct payments from downstream countries to facilities in upstream countries (Bernauer, 1996). Treaties that allocate water supplies frequently involve direct payments: Hamner and Wolf (1998) find 44 examples of such payments among the 54 water allocation treaties. Thus, we might fail to find a

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[2] Most of the growing theoretical literature on international environmental agreements focuses on global pollutants, such as greenhouse gases, which differ from the regional and directional pollution studied here. On the role of side payments and sanctions in that context, see Hoel, 1992; Carraro and Siniscalco, 1993; Chandler and Tulkens, 1994; and Barrett, 2001.

relationship between bilateral trade and shared resources if this history indicates that the political hurdles to direct payments are not very high.

Second, trade may facilitate cooperation as a threat to support demand for greater provision of shared environmental goods. This use of trade as a threat, sometimes called "linkage," promotes environmental cooperation in some models (Limão, 2002). Again, countries with extensive economic contacts may have more opportunities for linkage than countries with less contact.

Third, trade contacts allow countries direct leverage over each others' economy. In the absence of agreements, importing countries may impose environmental charges on imported goods based on their contribution to the pollution, such as the pollution content tariffs studied by Copeland (1996). Extensive trade raises the likelihood that the downstream country imports the polluting good.

Finally, trade may assist in environmental coordination because trade relationships have cultural implications. Upstream countries are more likely to make sacrifices on behalf of downstream countries who are viewed as friends. Trade may follow from such goodwill and also promote it, because economic activity requires personal contacts between people in the two countries. Neumayer (2002) looks at the association between general trade openness and multilateral environmental agreements in an attempt to test this goodwill link; however, this test lacks the specificity of the bilateral trade and environmental relationships studied here.

Any effects of trade on coordination would result from the extent of economic interaction between the countries, which depends not only on trade frictions but also on potential gains from trade given by the preferences and endowments of the two countries. In this way, these trade effects differ from the composition, scale, and technique effects from reducing trade frictions. One implication is that the trade intensity measure for the current study should reflect the amount of trade, not trade barriers as in the literature on trade and the environment.[3] As a second implication, the current study does not need to condition on the complementarity between the two economies: a large natural trade relationship is consistent with the hypotheses suggesting trade may be associated with better environmental coordination.

1.2 Scale, composition, and technique effects

A drawback of examining pollution levels rather than explicit agreements is that bilateral trade may affect the uncoordinated equilibrium as well as the results of policy coordination. Transboundary pollution levels may change with trade just as local pollution levels change from the composition, scale, and technique effects of overall trade that have been the focus of a growing empirical literature.[4] The estimated equations include a variable

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[3] For example, Reppelin-Hill (1999) and Damania et al. (2003) use measures based on import and export duties, in addition to openness.

[4] For recent empirical work, see Antweiler, Copeland and Taylor (2001) and Frankel and Rose (2002). For surveys, see Copeland and Taylor (2003) and Dean (1999).

for overall openness to distinguish the effects of bilateral trade from the general effects of trade on the environment.

However, special scale and composition effects may also result from bilateral trade. One scale effect of bilateral trade that may appear in these data results from the location of activity. If production of traded goods occurs near the border with the trading partner, then rivers that cross the border may have higher pollution with more trade. This scale effect will yield a positive link between exports and pollution, tending to counteract the policy coordination effects. As a result, any negative association between trade and pollution in the empirical analysis may understate the true effects of trade on coordination.

Nonuniformly mixed transboundary pollutants may also have a special composition effect. For these pollutants, damages from pollution are higher the farther upstream (or upwind) the activity is located because of greater exposed population. From the perspective of global welfare, downstream countries have a relative advantage in pollution-intensive activities because the farther downstream a pollution source is located downstream, the lower the external costs, all else equal. Thus, reducing trade frictions would move pollution downstream if environmental policies are coordinated and vary with exposure. This effect would appear in the empirical analysis as an effect of trade that raises pollution downstream and lower pollution upstream.

2. Data

2.1 Water pollution data

The United Nations' Global Environmental Monitoring System (GEMS) provides annual or triennial average pollution levels at river monitoring stations around the world from 1979 through 1996. Using a GIS, I coded the countries that share the river for each GEMS station. Of the 291 stations in GEMS reporting the pollutant studied here, 96 are "international" in the sense that they are upstream or downstream of international borders or located on a river when it forms a border between two countries. Lack of one or more of the explanatory variables reduced the sample to 247 stations, including 72 that are international (see Table 1). The largest number of stations excluded (23) are international stations that lack trade data.[5]

Figure 1 shows the international distribution of stations. As the map shows, the stations are located around the world, with especially heavy concentration in Europe. Overall 33% of stations and 22% of observations used in the analysis are in Europe. The European share of international stations is even larger: 47% of stations and 44% of observations.

Sample selection may be a problem in the GEMS data, although they have been used often in the environmental economics literature for lack of alternatives. Participating countries select monitoring stations without restrictions, but with the request from the GEMS

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[5] Trade data are missing for several reasons. Two stations report pollution only in 1979 before the trade series began. In addition, no data are available for trade between Belgium and Luxembourg and among the former USSR countries, which are grouped together in the data set. A few other countries, especially in Africa, lack data, presumably because their governments do not collect this information.

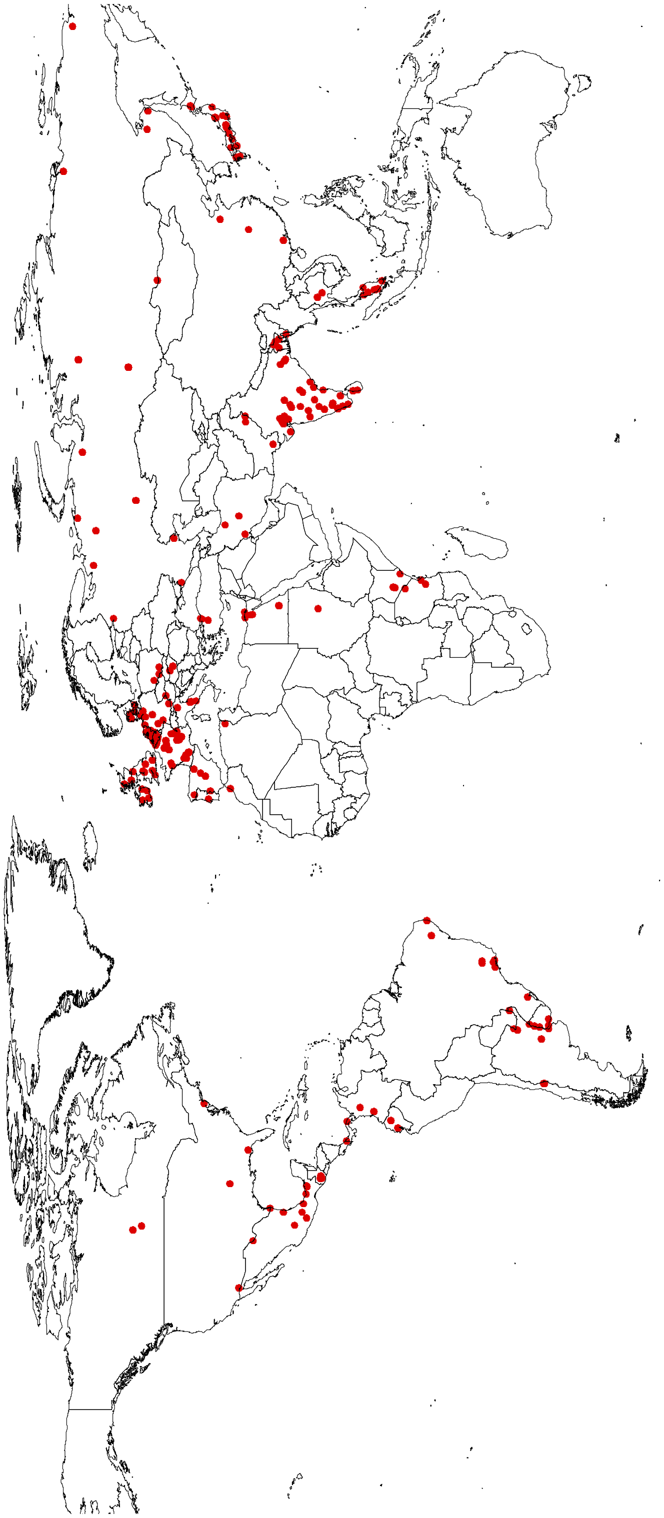

Figure 1: GEMS river monitoring stations used in the analysis

program that they choose locations with and without extensive human influence. For the current research, the greatest concern is that countries may strategically chose monitoring locations to reflect their bargaining interests. Upstream countries have an incentive to report cleaner water selectively, but downstream countries have the reverse incentive. Thus, the empirical analyses may provide evidence of such a bias by distinguishing upstream and downstream locations on international rivers.[6]

I use biochemical oxygen demand (BOD) as the pollution measure for several reasons. First, BOD is among the most common water quality measures in GEMS, providing many observations for analysis. Second, BOD levels are easily measured by standard procedures, which helps assure consistency in data quality across countries. Other pollutants, such as metals, are more difficult to measure, giving rise to greater data quality concerns. Third, elevated BOD is attributable to a range of human activities, especially sewage, so heterogeneity in local industrial activity is not very important to BOD levels. Fourth, BOD may travel reasonably far downstream, allowing significant spillovers at many stations on international rivers. It would be interesting to look at other pollutants, such as pathogens, that have a direct effect on human health. However, pathogens do not travel more than a few miles downstream, so cross-border spillovers are less important. Fifth, BOD (and oxygen depletion more generally) is a major focus of regulation. In the United States, for example, many more permits for point sources of water pollution address BOD than any other single pollution measure.[7] Thus, governments influence the level of this pollutant and can coordinate their choices.

Table 1 reports summary statistics for the observations used in the analysis, dividing the sample into international and domestic stations. The first column in Table 1 first reports average BOD concentrations. The water quality appears to be somewhat better on domestic rivers (BOD concentration of 5.6 milligrams per liter (mg/l)) than international ones (8.7 mg/l), as free riding might suggest. To help interpret these concentrations, consider that rivers with BOD higher than 4 mg/l are not acceptable for any recreational use (including boating) in the United States (Vaughan, 1986).

The reported pollution levels are annual mean concentrations at the station from 1979 and 1990 and triennial means for the next six years (for some stations, triennial means start in 1988). The second row of Table 1 reports that the means are based on an average of 14.8 measurements at international stations and 16 measurements at domestic stations, with substantial variability across stations.

2.2 Explanatory variables

Statistics Canada (1998) provides data on bilateral trade flows by country in current US dollars from 1980 through 1995. These data were deflated by the US Producer Price

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[6] A more thorough solution would model the selection of sites explicitly. However, such a model is difficult to estimate because the set of potential monitoring locations is infinite (anywhere along a river anywhere in the world). In addition, few characteristics are available for the unmonitored places.

[7] BOD accounts for 17% of National Pollution Discharge Elimination System (NDPES) permits in the 2003 Permit Compliance System. Dissolved oxygen accounts for the next largest percentage, 1%.

Table 1: Means and standard deviations of the data

	International stations		**Domestic stations**	
Variable	Mean	S.D.	Mean	S.D.
Mean BOD concentration (mg/l)	8.7	31.6	5.6	15.2
Number of measurements per observation	14.8	12.7	16.0	18.2
Downstream station (share)	.765		–	
Trade intensity if downstream (% of GDP)	1.62	1.88	–	
Upstream station (share)	.243		–	
Trade intensity if upstream (% of GDP)	7.15	6.46	–	
Border station (share)	.045		–	
Trade intensity if border (% of GDP)	18.7	39.1	–	
Upstream population	1.40	3.74	.82	2.91
GDP per capita (thousand 1996 dollars)	11.43	6.47	7.66	6.90
Political rights (1 (low) – 7 (high))	2.66	1.90	2.56	1.49
Other openness (% of GDP)	36.93	20.71	34.8	27.0
Flow (m^3/sec)	4603	8818	1210	3772
Flow data missing	.233		.087	
Deoxygenation rate (days^{-1})	.373	.104	.415	.133
Total observations	395		992	
Number of stations	72		175	

Note: Standard deviations for continuous variables only.

Index and merged with the GEMS data, using my coding of the upstream, downstream, and border countries for each station.

The analysis includes several measures of the importance of the trade with the downstream country to the upstream country's economy. Most equations use the bilateral version of the standard openness measure: the ratio of exports plus imports to total GDP. Trade intensity between an upstream country, u, and downstream country, d, is:

$$\text{Trade\_intensity}_{ud} = \frac{\text{Exports}_{ud} + \text{Imports}_{ud}}{\text{GDP}_u}, \tag{1}$$

where Exports_{ud} and Imports_{ud} are exports and imports from the upstream country to the downstream country and GDP_u is the upstream country's GDP.[8] Trade is scaled by the upstream country's GDP because the goal is to measure the downstream country's influence on the upstream economy. The station may be located in either the upstream or downstream country, so GDP_u may be own or upstream country's GDP. Robustness checks later in Section 3 use alternative trade intensity measures, such as export intensity only and total trade rather than its share of upstream GDP.

Table 1 reports the mean of this trade intensity variable separately for stations that are upstream and downstream of borders and for stations on a border. The estimated equations distinguish trade intensity by upstream and downstream location of the station for a few reasons. First, as mentioned above, distinguishing upstream and downstream stations helps address strategic reporting. Second, several stations are both upstream and downstream of borders. It is not clear which intensity measure to select for these stations. Distinguishing the two effects solves this problem by allowing a variable for each relationship to be included in the equations. Third, distinguishing these effects allows the possibility of different effects at upstream and downstream stations. At upstream stations, any elevated pollution results from free riding by that country. At downstream stations, the pollution reflects the higher endowment of the pollution from upstream less any additional pollution control that the downstream country exercises in response to the dirtier water it receives. As a result, cooperation may have smaller effects on downstream pollution levels than upstream levels. In addition, as argued above, the composition effect of trade may shift pollution to the downstream country.

Several of the stations are located on a river when it forms a border between two countries. These stations present a different sort of negotiation regime than the remaining stations. Each country is both a polluter and a victim, perhaps giving rise to a richer set of negotiated solutions and reducing the need for nonenvironmental linkages. These stations also present a technical problem for the analysis: the trade intensity measure requires selecting a country for GDP in the denominator. To avoid arbitrary assignments, I defined trade intensity for border stations as the average intensity between the two countries.[9]

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[8] The denominator is the only thing that keeps this definition of trade intensity from being symmetric between the upstream and downstream country because $\text{Exports}_{ud} = \text{Imports}_{du}$ and $\text{Imports}_{ud} = \text{Exports}_{du}$.

[9] The numerator of this measure is the same for both stations because of the symmetry of exports plus imports, so the averaging just affects the denominator.

Table 1 shows that the majority of international stations (76.5%) are downstream of a border. The mean trade intensity for these stations is 1.6% of the upstream country's GDP (with a mean of 3.3% when the borders are between EU countries and .5% when the borders they are not). This value ranges in the data from slightly more than nearly zero to 8%. A higher mean, 7.2%, characterizes the upstream stations, where the maximum trade intensity is 18%.

Table 1 also reports a number of other explanatory variables. These variables were chosen to reflect the costs and benefits of achieving given pollution levels on a river. They include upstream population, country characteristics, and river characteristics.

The 1994 population upstream of the station is included as a measure of uncontrolled pollution at the station. I used a GIS to construct this variable from the 1994 Gridded Population of the World (Tobler et al., 1995) and data on flow direction from the US Geologic Survey's Global Hydro1K database. Hydro1K contains the direction that water flows in a grid of 1 km by 1 km cells (based on the cell's altitude relative to its neighbors). The "flow accumulation" function of ArcView then makes it possible to estimate the upstream drainage area for all cells in the grid. Weighting the upstream cells by their estimated population causes "flow accumulation" to return a grid of total upstream population, which was then used to attribute upstream population to the location of the station. The upstream population values are noisy because the calculated location of the river (based on flow accumulation) sometimes does not correspond to its actual location.[10] However, these miscalculations do not seem to introduce any systematic bias from the perspective of the current analysis. Table 1 reports higher upstream population along international rivers than domestic rivers, as might be expected.

Several characteristics of countries are included. National per capita income may affect the costs of pollution control and the benefits of water quality. The Penn World Table (Heston et al., 2001) provides annual income levels standardized for cross-country comparisons.[11] Participating countries are relatively high income: as Table 1 reports, income averages over \$11,000 per capita in 1996 dollars at international stations and \$7,000 at domestic stations. International stations have higher income because of the dominance of European observations within this sample. Some previous studies have found that pollution rises and then falls with income, a pattern sometimes called the "environmental Kuznets curve" (Selden and Song, 1994; Grossman and Krueger, 1995). The estimated equations include a quadratic in income to control for these effects.

In addition, the equations include a measure of general openness to trade. An open country is likely to trade extensively with its neighbors. If a country's openness also affects

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[10] I believe these differences result from insufficiently fine resolution of the Hydro1K flow direction grid. An alternative approach to calculating upstream population would be to count upstream cities manually. However, this approach is difficult for complex river systems, with many tributaries to take into account. It also might introduce systematic error by overrepresenting population in places with high urban concentration relative to more rural areas.

[11] When the Penn World Table 6 does not provide data, I have interpolated it by rescaling data from earlier Penn World Table versions or from the World Bank.

pollution levels (as previous research on trade and the environment suggests), then failure to include openness could bias the coefficients on the bilateral trade measures. Therefore, the estimated equations include an adjusted version of the standard openness measure, total exports plus total imports divided by GDP, for the country in which the station is located. To reduce collinearity, the adjusted version of openness excludes bilateral trade with the country with which the river is shared.

A final country attribute is a measure of the political structure of the country. Earlier research has suggested that more responsive governments are likely to choose lower pollution than autocratic regimes (Congleton, 1992; Barrett and Graddy, 2000). Freedom House (2004) annually evaluates countries' "political rights" on a scale from 1 (lowest) to 7 (highest). Despite the high income of countries in the data, the average political rights score is only 2.6.

Geography may affect the country attributes relevant at a given station. At stations downstream of borders, conditions in the upstream country as well as the country of the station may be influential. For this reason, most of the estimated equations also include GDP, openness, and political rights of the upstream country as well as the country of the stations. At stations on borders, two countries' data are equally relevant. To avoid arbitrarily selecting one country, all the country-level variables for border stations (GDP, openness, and political rights) are the mean of the values for the two neighbors.

Finally, several river characteristics are included. First, the river flow determines dilution rates and thus the effect of waste input on in-stream pollution concentrations. This dilution would lead one to expect an inverse relationship between river flow and pollutant levels. Second, the time rate of exponential decay of BOD (known as the "deoxygenation rate," k) is used as a measure of the speed of natural attenuation. I calculated this value from the GEMS data on river temperature, using a nonlinear function from the scientific literature (Bowie et al., 1985).

3. Results

The estimated equations have the form

$$\log b_{it} = g(TI_{it}, Pop_i, CountryChar_{it}, RiverChar_{it}, t) + \varepsilon_{it}, \tag{2}$$

where b_{it} is the mean pollution concentration at station i in year t, TI_{it} (which is TI_{ud} for the upstream and downstream countries at station i in year t) is a matrix of trade intensity variables. Except with station fixed effects, equations also include dummy variables for the location of the station — whether it is upstream, downstream or on a border river — so that zeros can be entered for irrelevant trade intensity variables (e.g., for all trade intensity variables at domestic stations). Pop_i is upstream population for the station in 1994. Country characteristics, $CountryChar_{it}$, include income, openness, and political rights. River characteristics, $RiverChar_{it}$, include flow and the deoxygenation rates. A trend, t, is included to capture changes over time in pollution control technology and environmental preferences. Some of the equations also include country or station fixed effects.

A log-log functional form was chosen for the estimated equation because factors that affect the uncontrolled pollution levels, such as upstream population and river flow, seem likely to have multiplicative effects. The log-log specification has two exceptions. GDP variables enter the equation with a quadratic in levels to follow approximately the specifications used earlier literature such as Grossman and Krueger (1995) and Antweiler et al. (2001). The deoxygenation rate, k_{it}, enters in levels because of the exponential decay function for BOD.

The error, ε_{it}, has a few characteristics that are taken into account in the estimation. First, BOD levels for any observation are the mean of multiple measurements. Because differences in the number of measurements cause heteroskedastic errors, the equations are estimated by weighted least squares with the number of measurements as weights. Second, errors at a single station across multiple years are likely to be correlated. To address this problem, the standard errors are adjusted for clustering at the station level.

3.1 Basic equations

Table 2 reports the results of estimates of equation (2). I will discuss the estimates of the coefficients on the trade measures first, followed by the other covariates.

3.1.1 Trade measures

The first equation in Table 2 does not include country effects. In this equation, the estimated coefficients on bilateral trade are statistically insignificant for all locations. The point estimates on trade at downstream stations and upstream stations have the expected negative sign, but a positive effect is estimated at borders.

The second equation in Table 2 adds country effects to account for heterogeneity across countries not adequately captured by the explanatory variables. Although addressing this heterogeneity is desirable, country effects may absorb some relevant variation in pollution levels. If countries must set environmental policies at a national level, they may not be able to reduce pollution only on rivers shared with countries with whom they have an extensive trade relationship. However, they might still free ride by choosing lower national pollution control than socially optimal. The effect of trade on these deviations will not be detected with country effects.

With the inclusion of country effects in column 2, a negative coefficient is estimated on trade at both downstream stations ($-.110$) and upstream stations ($-.389$). The coefficient is statistically significant at the 5% level at downstream stations and at the 10% level at upstream stations. The equations are consistent with the hypothesis that free riding occurs but is mitigated by trade. The upstream and downstream station dummies both have positive coefficients, suggesting a detrimental effect of the border with no trade, whereas trade seems to lower pollution. Combining the two effects for downstream stations, pollution is still slightly higher at downstream stations at mean trade intensity. For the maximum value of trade intensity at downstream stations, the net effect of the two variables is about a 60% reduction in pollution. Although this combined effect is inconsistent with the coordination

Table 2: Weighted least squares estimates with and without country fixed effects

	Dependent variable: Log (Mean BOD)					
	(1)		(2)		(3)	
Country fixed effects?	No		Yes		Yes	
Downstream station	.485	(.313)	.709	(.294)	.061	(.712)
Log(Trade intensity) if downstream station	-.047	(.043)	-.110	(.039)	-.232	(.076)
Upstream station	.531	(.462)	.809	(.551)	.682	(.571)
Log(Trade intensity) if upstream station	-.076	(.131)	-.389	(.210)	-.387	(.214)
Border station	-.630	(.480)	-.728	(.261)	-1.14	(.388)
Log(Trade intensity) if border station	.308	(.138)	.199	(.091)	.314	(.112)
Log(Upstream population)	.052	(.025)	.076	(.026)	.074	(.026)
Own country charactistics:						
GDP per capita	.054	(.060)	.018	(.059)	.030	(.061)
GDP per capita squared	-.0033	(.0022)	-.0005	(.0019)	-.0007	(.0020)
Log(Other openness)	.214	(.139)	.101	(.127)	.078	(.131)
Log(Political rights)	-.241	(.134)	-.139	(.111)	-.082	(.125)
Upstream country char.:						
GDP per capita	–		–		.180	(.078)
GDP per capita squared	–		–		-.0048	(.0019)
Log(Other openness)	–		–		.037	(.196)
Log(Political rights)	–		–		.427	(.222)
River characteristics:						
Log(Flow)	-.104	(.039)	-.052	(.030)	-.048	(.029)
Flow missing	-.124	(.448)	.045	(.504)	.082	(.507)
Deoxygenation rate, *k*	1.263	(.559)	-1.71	(.914)	-1.60	(.914)
Year	.022	(.009)	.0009	(.0076)	-.0005	(.0081)
Intercept	-1.57	(.725)	–		–	
R^2	.19		.40		.40	
Number of observations	1387		1387		1381	
Number of stations	247		247		247	

Notes: Weighted by number of measurements.
Standard errors (in parentheses) robust to clustering at the station level.

hypothesis, it is not statistically different than zero. Thus, an inference is that free riding occurs, but sufficient trade overcomes it.

At the point estimates, the estimated elasticity is higher at upstream stations than downstream stations. Although this difference is not statistically significant, it does contradict the special composition effect described in section 1 in which freer trade allows industry to move to the lower reaches of a river where exposure is lower. This effect would have given rise to a negative coefficient upstream and a positive coefficient downstream because polluting industries should end up downstream.

The coefficient on intensity at border stations has a positive and statistically significant coefficient (.199 in the equation in column 2). This positive coefficient could be the scale effect mentioned above: production of traded goods occurs near the relevant border, resulting in higher pollution. This effect may be strongest for border rivers because the area near the river accounts for a larger share of the border region than for upstream or downstream stations. For upstream-downstream relationships, places where highways — rather than rivers — cross the border may be a greater focus of trade-directed production. However, the data contain only a small number of border stations (11 stations), so results for borders should be treated as somewhat anecdotal.

Column 3 adds characteristics of the upstream country for downstream stations. The variables may affect the condition of the river bestowed upon a country from its upstream neighbors. Their inclusion strengthens the point estimate of the effect of trade at downstream stations (from $-.11$ in column 2 to $-.23$ in column 3).

3.1.2 Other determinants

Upstream population has a statistically significant and positive coefficient in all the equations in Table 2. The estimated elasticity of pollution to population is fairly low, however, only .076 in column 2. This coefficient may reflect downward bias from measurement error, given the problems calculating this value discussed above.

The country characteristics do not have strong effects on pollution levels. The relationship between the log of pollution and log of GDP follows an inverted U-shaped pattern, but the coefficients are not individually or jointly statistically significant at 5% in any of the equations. Equations estimated with higher order polynomials in income (not shown in Table 2) also did not have statistically significant coefficients on income and had similar coefficients on trade intensity. The coefficient on other openness is not statistically significant at the 5% level in any of the estimated equations.[12] Political rights also do not have a statistically significant effect on pollution, although the point estimate is negative, as expected.

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[12] The equations were also estimated with an interaction between this other openness variable and GDP, in the spirit of the equations of Antweiler et al. (2001). The interaction is included because countries at different income levels may have different techniques of production and thus experience different effects from trade openness. The interaction was not statistically significant in any equation and is not shown in the tables.

When the characteristics of any upstream country are added in column 3, upstream GDP and political rights have statistically significant coefficients with the expected signs.[13] However, although these coefficients are individually statistically significant, an F-test fails to reject that the upstream country coefficients are jointly zero.

The river characteristics enter with the expected signs. The coefficient on river flow rate is negative across all equations as expected. It is statistically significant at 5% in column 1 and 10% with country effects in column 2. A negative coefficient is expected on the deoxygenation rate, k, because the variable is a decay rate for BOD. Except in column 1, a statistically significant negative coefficient is estimated.

Finally, the time trend is statistically significant only when no fixed effects are included in column 1. In this column, the time trend is positive. These results suggest that GEMS expanded over time to include countries with more polluted rivers, but do not indicate dramatic improvement within countries in pollution concentrations.

3.2 Station fixed effects

Table 3 contains estimated coefficients with effects for station-level unobserved heterogeneity, such as local economic activity and river conditions. Station fixed effects should absorb most of the heterogeneity that might arise from differences in land use upstream from the station, which does not change very rapidly over time.[14] The upstream population estimate used in earlier equations cannot be included with fixed effects because it does not vary over time. To measure some population trends, this equation instead includes the population of the country of the station and, for downstream stations, the upstream country. Excluding upstream population permits a somewhat larger sample; 19 stations excluded earlier for lack of these data are now included, bringing the number of stations up to 266 for the station fixed-effects equation.

With these station fixed effects, all trade intensity variables have statistically insignificant coefficients. The failure to find effects may support the hypothesis that the observed effect of trade on pollution is a coordination effect rather than a scale effect. Short run fluctuations in trade are unlikely to influence the ability of countries to coordinate and thus the purely time-series identification in Table 3 would fail to yield results. By contrast, if the negative association results from more direct production-related factors, we would expect an immediate pollution response and an effect in Table 3. Only the positive coefficient on trade at border stations retains its magnitude from Table 2 to Table 3. The robustness of this coefficient is consistent with the hypothesis advanced above that the coefficient is driven by the scale effect.

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[13] Although it may appear that upstream country characteristics are more likely to matter than own country characteristics, this inference fails to recognize the difference in identification of the two sets of coefficients. The equation includes own country fixed effects, so the identification for own country effects comes only from time series variation, whereas the upstream country effects also rely on cross-sectional variation.

[14] With station-level fixed effects, Sigman (2003) finds no effect of changes the share of land in agriculture or urban uses on water quality at river monitoring stations in the U.S.

Table 3: Weighted least squares estimates with station fixed effects

	Dependent variable: Log (Mean BOD)	
Log(Trade intensity) if downstream station	-.002	(.069)
Log(Trade intensity) if upstream station	.039	(.206)
Log(Trade intensity) if border station	.254	(.163)
Own country charactistics:		
GDP per capita	-.056	(.055)
GDP per capita squared	.0012	(.0016)
Log(Other openness)	.146	(.102)
Log(Political rights)	-.130	(.069)
Log(Population)	.665	(.577)
Upstream country characteristics:		
GDP per capita	.132	(.102)
GDP per capita squared	-.0047	(.0036)
Log(Other openness)	.303	(.186)
Log(Political rights)	.459	(.228)
Log(Population)	-.314	(.556)
River characteristics:		
Log(Flow)	-.017	(.027)
Deoxygenation rate, *k*	-1.15	(.431)
Year	-.006	(.012)
R^2	.84	
Number of observations	1500	
Number of stations	266	

Notes: Weighted by number of measurements.
Standard errors (in parentheses) robust to clustering at the station level.

Few of the other determinants have statistically significant coefficients in Table 3. The country population variable does not enter statistically significantly, perhaps because of its failure to capture local conditions adequately. Country characteristics also do not enter this equation. Turning to the river characteristics, flow does not have a statistically significant coefficient perhaps because of data limitations. Time-varying flow data are available only for the last six years and, even then, for a subset of the stations. On the other hand, the deoxygenation rate is one of the few statistically significant coefficients in the station effects equation. Interestingly, the point estimate of this coefficient is stable between the country and station effects equations.

3.3 Alternative specifications

Table 4 reports the results for alternative specifications, including different measures of trade intensity. The covariates in the equations are the same as in column 3 of Table 2, but have been suppressed in Table 4 to allow a focus on the coefficients of interest.

In the first row of Table 4, trade intensity depends only upon exports from the upstream country to the downstream country. Upstream politicians are more likely to respond favorably to offers that increase their exports than their imports. The estimated coefficient on trade at downstream stations is now statistically significant only at the 10% level. However, the overall results are similar to the results with the more inclusive trade intensity measure.

The second row of Table 4 redefines trade intensity to depend on the absolute value of exports plus imports between the two countries, rather than their values relative to upstream GDP as in Table 2. Pollution reduction requires an expenditure for which the upstream country would like to be compensated, so the ability to provide a sufficient absolute sum could be more relevant than the share of GDP. This redefinition does not much change the estimated effect of trade at upstream stations. The point estimate at downstream station becomes positive but statistically insignificant. The latter result raises some questions about the robustness of the estimated relationship; however, the trade intensity measure used in Table 2 is more compelling than this measure.

The next two rows in Table 4 address the geography of the relationships in more detail. The third row excludes observations on rivers when they form country borders. Border stations do not fit into the basic conceptual framework in which the downstream country demands — and the upstream country supplies — environmental quality. At border stations, trade may play less of a role because both countries are in both positions with perhaps more room for agreements without linkages. In addition, it is technically difficult to chose intensity measures for border stations. For example, when border stations are also downstream, the intensity measure includes trade between the upstream country and the reporting country, but not its neighbor's trade with the same country. Eliminating border stations gives results similar to those in column 3 of Table 2. Both downstream and upstream influence are negative and statistically significant.

The fourth row of Table 4 addresses the effect of distance to the border. If trade influences pollution through coordination, this effect should only be seen where transboundary

Table 4: Weighted Least Squares estimates for alternative specifications

Specification	Trade intensity at downstream station	Trade intensity at upstream station	Trade intensity at border station
Trade intensity= $\frac{\text{Exports}_{ud}}{\text{GDP}_u}$	-.135	-.464	.243
	(.075)	(.235)	(.107)
Trade intensity= $\text{Exports}_{ud} + \text{Imports}_{ud}$	.006	-.337	.090
	(.058)	(.167)	(.064)
Exclude border stations	-.237	-.388	–
	(.076)	(.223)	
Trade intensity only for stations within 100 miles of border	-.295	-.379	.164
	(.097)	(.201)	(.071)
Distinguish borders within EU from all others			
EU	-.102	-.409	.153
	(.064)	(.228)	(.117)
Non-EU	-.193	.087	.144
	(.069)	(.184)	(.209)
p-value of test of equality	.018	.023	.94
Distinguish by upstream political conditions			
Low political rights	-.241	-.370	.305
	(.084)	(.224)	(.160)
High political rights	-.234	-.433	.314
	(.077)	(.214)	(.107)
p-value of test of equality	.80	.46	.92

Notes: Full equations as in column 3 of Table 2.
Standard errors (in parentheses) robust to clustering at the station level.
Excluding border stations reduces the sample to 1307 observations and 236 stations.

spillovers occur. Far upstream of a border, the vast majority of the pollution costs are borne by the upstream country both because its exposure is greater and because BOD attenuates as water flows downstream. Similarly, far downstream of a border, most pollution from the upstream country should have attenuated, so we would not expect an effect of coordination. To address this geography, the fourth row shows the equations when the upstream and downstream trade intensity variables enter only if the station is within 100 miles of the border. Although one might expect more negative coefficients on trade with this modification, the estimates in Table 4 remain similar in magnitude to those in Table 2. At downstream stations, the point estimate goes from $-.232$ (column 3 of Table 2) to $-.295$ (4th row of Table 4) and changes even less at upstream stations.

The last two sets of rows in the Table 4 report interaction effects of particular interest. One set of interactions distinguishes the effects of trade inside and outside the European Union. Trade may have less of an effect inside the EU than outside for several reasons. First, centralized environmental institutions within the EU may make bilateral side payments or threats unnecessary. Supporting this view, Sigman (2002) finds that EU stations exhibit less evidence of free riding than other stations on international rivers. Second, explicit side payments may be more readily available for countries already cooperating on other policy matters, as the example of chlorine pollution in the Rhine suggests.

The results are somewhat mixed about these hypothesized differences between within-EU and other borders. At downstream stations, we see the anticipated pattern. The coefficient for trade at EU stations is negative ($-.102$), but not statistically different than zero, suggesting little or no effect of trade. For borders not between EU members, the trade coefficient is negative ($-.193$) and statistically significant. In addition, the difference between the two coefficients is statistically significant. However, at upstream stations, the results are less supportive. Neither coefficient is now statistically significant at 5%. The point estimate within the EU is more consistent with an effect of trade on policy coordination, whereas the point estimate is positive outside the EU. The data set includes very few upstream stations outside the EU, so one explanation is that the data are not rich enough for a reliable test of the hypothesis at upstream stations.[15]

The final set of interactions in Table 4 consider the effects of differences in political regimes. Countries with more responsive governments may be more willing to reach negotiated solutions to environmental problems with neighbors. Dividing the trade effects according to whether the country has a closed regime or open regime (where closed regimes have Freedom House political rights scores of two or less), one finds no evidence of a distinction. All the point estimates are very close to their earlier values. The coefficients at upstream stations are no longer individually statistically significant; as with the EU distinction, this change may result from the small number of observations in this sample.

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[15] In the equations with the EU distinction, the coefficient on trade intensity for border countries are no longer statistically significant, raising some questions about the robustness of the positive effect estimated elsewhere.

3.4 Endogeneity of bilateral trade

The equations estimated above do not determine the direction of causality of any link between trade and pollution in shared rivers. A negative coefficient on trade might indicate that trade relationships facilitate reaching common environmental goals. However, it may also indicate that countries that have achieved environmental coordination expand their trade. If the causality goes this direction, it still suggests a role for trade in supporting environmental negotiations. Nonetheless, one could not then draw the policy implication that expanded trade will help resolve international environmental disputes.

To try to distinguish the first effect from the second, this subsection presents results for equations that instrument for trade intensity. The instruments are based on "gravity" models that use geographic characteristics of trading partners to predict their trade. Frankel and Romer (1999) use two measures of the size of the two countries, area and population, and their landlocked status.[16] Thus,

$$TI_{it} = g(A_{ui}, A_{di}, P_{uit}, P_{dit}, LL_{ui}, LL_{di}, CountryChar_{it}) \tag{3}$$

where A_u and A_d represent the land area of the upstream and downstream country at station i, and P their populations, and LL their landlocked status. Country population is the only time-varying instrument. The exclusion restrictions to identify the model require that these country-level measures do not affect pollution in a specific river. This assumption is easiest to maintain for country areas. For population, the restriction requires that the station-specific upstream population measure accurately captures the influence of population and that country-level measures do not add relevant information.

Instrumental variables estimates require instruments for three variables: trade intensity at upstream stations, downstream stations and border stations. Thus, the full set of instruments includes area and country population and landlocked status of the country of the monitoring station, any upstream country, any downstream country, or any border country. The variables have values of zero when not relevant for any station. The instrumental variables equation is the same equation as in column 3 of Table 2, including state fixed effects and upstream country characteristics.

Table 5 presents the instrumental variables estimates, which remain similar to their earlier values. Trade intensity continues to have negative and statistically significant coefficients at downstream and upstream stations and positive and statistically significant coefficients at border stations. Trade intensity at downstream stations now has a more negative point estimate ($-.42$) than before ($-.23$). Other coefficients in the equation also do not change markedly. A Hausman test of the OLS specification in column 3 of Table 2 against the IV specification in column 2 fails to reject the exogeneity of the trade intensity

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[16] In addition, they use a series of interactions of these variables for whether countries are neighbors. These variables are not available because all relationships are between neighbors in this study. Frankel and Romer sum predictions of bilateral trade across many partners to form an aggregate predicted openness, which is their instrument. However, the bilateral relationships are included in the main equation here, eliminating the need for this intermediate step.

Table 5: Instrumental variables estimates

	Dependent variable: Log (Mean BOD)	
Downstream station	-.069	(.559)
Log(Trade intensity) if downstream station	-.423	(.175)
Upstream station	.510	(.587)
Log(Trade intensity) if upstream station	-.351	(.143)
Border station	-1.73	(.559)
Log(Trade intensity) if border station	.484	(.154)
Log(Upstream population)	.073	(.026)
Own country charactistics:		
GDP per capita	.050	(.061)
GDP per capita squared	-.0013	(.0020)
Log(Other openness)	.021	(.148)
Log(Political rights)	-.059	(.119)
Upstream country characteristics:		
GDP per capita	.314	(.138)
GDP per capita squared	-.0078	(.0031)
Log(Other openness)	.137	(.187)
Log(Political rights)	.675	(.336)
River characteristics:		
Log(Flow)	-.051	(.031)
Flow missing	.049	(.509)
Deoxygenation rate, *k*	-1.42	(.915)
Year	.0008	(.0082)
Number of observations	1361	
Number of stations	245	

Notes: Weighted by number of measurements.
Standard errors (in parentheses) robust to clustering at the station level.
Country effects included.

measure (chi-squared 1.19). This failure could indicate that trade levels are unaffected by environmental coordination. However, the test does rely on the IV specification as a maintained hypothesis.

4. Conclusion

The empirical analysis presented here supports the view that trade promotes environmental cooperation. Countries with more extensive trade have lower pollution in rivers they share than other countries, with estimated elasticities of BOD to trade intensity (exports plus imports between the two countries as a share of upstream GDP) in the range of $-.1$ to $-.4$. The results are consistent with countries free riding, but overcoming it with sufficient trade. Neither varying the trade intensity measure nor addressing the possible endogeneity of trade using gravity instruments substantially alters the estimated effect.

In addition, the study examines conditions in which trade is effective. Trade may be more important across borders that are not within the EU, suggesting that trade linkages are unnecessary to resolve EU environmental disputes. However, the results did not suggest that trade plays a larger role when the upstream country is more open politically.

A negative association between trade and pollution was not observed under two conditions. First, stations on the border between countries appear to have increases in pollution with increased trade. This effect seems likely to be the result of a scale effect of trade: economic activity and hence pollution may be higher near the border river. Second, when monitoring station (rather than country) fixed effects are included in the analysis, the trade intensity variables are not significant. However, the fluctuations over time in trade that identify this equation may not influence the ability of countries to coordinate environmental policies.

The results have positive implications for international environmental policy. First, they suggest that, despite incentives to free ride, countries are able to exercise influence over each other's pollution control levels. Thus, they provide some reason for optimism about negotiated solutions to international spillovers. Second, the results suggest that improvements in coordination from expanded trade may yield environmental benefits to weigh against environmental costs from the pollution havens effect.

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