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International Trade and Pollution in Shared Resources: A Study of International Rivers

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Abstract: This paper examines whether trade relationships facilitate resolution of international environmental spillovers. Using data from the UN's Global Environmental Monitoring System (GEMS) on water quality in international rivers, I examine the influence of bilateral trade on pollution in rivers that cross international borders. There is little evidence of lower water pollution in rivers shared between countries with more extensive trade, with a small effect possible only outside the European Union.

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International trade may help resolve transboundary environmental disputes. Countries with extensive trade have more opportunities for implicit side payments to support agreements than countries with limited economic contacts. Trade relationships may also make threats available to encourage greater provision of shared environmental goods.

This paper examines whether trade encourages greater environmental quality in shared resources. Rather than using explicit agreements, it studies the effects of environmental decision-making as revealed by pollution levels. I look specifically at pollution in rivers that cross national borders to determine if the intensity of trade affects observed environmental quality.

Rivers provide a good opportunity to test the effect of trade relationships for several reasons. There are many different rivers, each representing a distinct resource; regional or global resources do not provide the opportunity to observe so many different outcomes. 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. In addition, 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 if there is some hope of coordination. Rivers present relatively simple environmental negotiation problems because of the small number of parties and well-understood nature of the pollution. Therefore, we might expect a greater role for trade here than in some other international environmental arenas, where there is little chance of any coordination between countries.

Data on pollution levels in international rivers around the world derives from the United Nations' Global Environmental Monitoring System (GEMS). I matched GEMS data to data on bilateral trade between the countries sharing the river from Statistics Canada (1998). Other explanatory variables include country income, upstream and local population calculated using a Geographic Information System, and other river characteristics that may affect pollution. I study biochemical oxygen demand (BOD), a common form of pollution for which earlier research shows evidence of free riding by upstream countries (Sigman, 2001).

The results provide little support for the hypothesis that trade facilitates environmental cooperation. In most equations, there is no effect of bilateral trade between countries sharing the river. The trade intensity measure does have a negative effect on pollution in international rivers outside the European Union (EU). However, even this effect is substantively small.

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, with and without country and station fixed effects. It also presents equations that vary the definition of trade intensity and that attempt to address the potential endogeneity of the trade measure. Section 4 briefly discusses the implications of the results.

1 Agreements, trade, and transboundary pollution

There are several ways that trade between two countries may affect pollution in resources they share. One effect is on the countries' ability to reach explicit or implicit agreements that overcome incentives to free ride.²

Although there are a large number of explicit agreements that address freshwater, most principally concern water supply and hydropower. Of the 150 treaties included in the Transboundary Freshwater Dispute Database, only a handful principally concern pollution (Hamner and Wolf, 1998).³ In this research, I focus on realized pollution levels rather than agreements for a few reasons. Explicit agreements may not constrain behavior, so the pres-

²Most 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, 1997 and 2001.

³Hamner and Wolf (1998) describe 6 (4%) of 145 treaties as principally addressing pollution. The current web version of their data set includes 150 treaties but only 4 are listed as principally concerning pollution, covering the Aral Sea (2 treaties with very similar content), transboundary rivers between Papua New Guinea and Indonesia, and the Elbe River. Another classification, "industrial uses," may also include pollution components. The data set is available at <http://terra.geo.orst.edu/users/tfdd/>.

ence of a treaty does not prove coordination (Conte Grande, 1997; Murdoch, Sandler, and Sargent, 1997; Congleton, 1995.) In addition, countries may reach accommodation that they choose not to formalize with a treaty.

Implicit and explicit agreements for rivers are likely to require side payments from the downstream countries to the upstream polluting countries (Mäler, 1990). However, there may be significant constraints on these side payments in practice. Governments are likely to find it politically difficult to make substantial direct payments to other governments or to pollution sources in other countries. Countries with more extensive economic contacts may find these contacts 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. Economic contacts may also reduce free riding even in the absence of agreements, if they induce countries to take greater account of each other's welfare.

Treaties provide some evidence of use of trade-related compensation. For example, 1993 and 1995 treaties concerning pollution in the Aral Sea contain language that suggests trade: the parties recognize as common objectives "creating most favored nation treatment conditions, and granting privileges and protection measures to the investors that put their funds into the programs and works aimed at environmental sanitation and social and economic development of the region."⁴

However, direct side payments for pollution reduction do 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, it is an empirical question whether there are sufficient obstacles to direct side payments for trade to play a role.

⁴According to Hamner and Wolf (1998), 43% of freshwater treaties include some "non-water linkages." However, their classification does not distinguish commitments that might be considered direct side payments, such as constructing wastewater treatment facilities, from more general economic concessions. Also, there may be concessions not mentioned as linkages in a treaty.

In addition to its potential to facilitate side payments, trade may also play a role as a threat to support demand for greater provision of shared environmental goods. Again, countries with extensive economic contacts may provide more opportunities for sanctions than countries with less contact. It is hard to identify examples of trade sanctions used to deter freshwater pollution specifically. The costs of trade sanctions may be too high relative to the benefits of reduced transboundary water pollution for them to be used or trade agreements may prevent the use of trade sanctions. However, failure to see trade sanctions explicitly invoked does not prove that they are irrelevant; the implicit threat of economic sanctions may play a role in negotiations.

A drawback of examining pollution levels rather than explicit agreements is that bilateral trade may affect the uncoordinated equilibrium as well as policy coordination. Trade with resource partners may give rise to the composition, scale, and technique effects of overall trade that have been the focus of a growing empirical and empirical literature.⁵ The estimated equations include a variable for overall openness to distinguish the effects of bilateral trade between resource partners from the general effects of trade.

With nonuniformly mixed transboundary pollutants, however, there also may be a composition effect that is specific to bilateral trade between resource partners. For these pollutants, the location of pollution matters, resulting in upstream and downstream (or upwind and downwind) countries. Downstream countries should specialize in the pollution-intensive industries because there is less exposure to pollution downstream. 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 higher pollution downstream and lower pollution upstream with higher trade.

The effects of trade on coordination result from the extent of economic interaction between the countries. The extent of this interaction will depend not only on trade frictions but also from potential gains from trade given by the preferences and endowments of the

⁵For recent empirical work, see Antweiler, Copeland and Taylor (2001) and Frankel and Rose (2002), and for surveys, Copeland and Taylor (2002) and Dean (1999).

two countries. In this way, these trade effects differ from the composition, scale, and technique effects, which result from reducing trade frictions. One consequence of this difference is that the trade intensity measures should reflect the amount of trade, not the trade barrier measures sometimes used in the literature on trade and the environment.⁶

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 Geographic Information System (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 upstream or downstream of country borders or located on a river when it forms a border between two countries. No trade data are available for 23 stations, reducing the sample to 73 stations.⁷

Table 1 reports the country pairs used in the analysis. The stations are found in all regions of the world, but are heavily concentrated in Europe. European countries disproportionately participated in GEMS. In addition, restricting the sample to rivers that cross national borders selects for locations in Europe as opposed to countries with larger area.

Sample selection may be a significant 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, with guidance asking them to choose locations with and without extensive human influence, but no other restrictions. For the current re-

⁶For example, Reppel-Hill (1999) and Damania et al. (2001) use measures based on import and export duties, in addition to openness. These measures are ruled out by the consideration in the text and also are not available on a bilateral basis.

⁷There are several reasons for lack of trade data. Two stations report data only in 1979 before the trade series began. In addition, there are no data for trade between Belgium and Luxembourg and among the former USSR countries and some other missing data, especially for African countries.

Table 1: Country pairs used in the analysis

Station location	Upstream country	Downstream country	Border country	Number of stations
Europe				
Belgium		France		1
Belgium			France	1
Belgium		Netherlands		1
Belgium	France			4
Belgium	France	Netherlands		1
France	Spain			4
France	Switzerland			8
Germany			Austria	1
Germany		Netherlands		1
Germany	France			1
Germany	France	Netherlands		1
Hungary	Czech Republic	Yugoslavia		2
Netherlands	Germany			3
Netherlands			Germany	1
Poland	Czech Republic	Germany		2
Poland	Czech Republic		Germany	1
Portugal	Spain			1
Russia	Finland			1
Spain		Portugal		4
Americas				
Argentina	Brazil		Paraguay	1
Argentina	Brazil		Uruguay	1
Argentina	Paraguay			4
Mexico	Guatemala			2
Mexico			United States	3
Panama	Costa Rica			1
United States			Mexico	1
Uruguay	Argentina		Brazil	1
Uruguay	Brazil		Argentina	1
Asia				
Bangladesh	India			5
Pakistan	India			3
Russia	China			1
Thailand	Laos			1
Africa				
Egypt	Sudan			7
Sudan	Eritrea	Egypt		1
Total				73

search, 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 incentives. Thus, it is possible to look for evidence of such a bias in the empirical results by distinguishing upstream and downstream locations on international rivers.⁸

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. 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.

Table 2 reports average BOD concentrations in the sample of 8.6 mg/l. These values indicate poor water quality. Rivers with BOD higher than 4 mg/l are not considered 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 number of measurements on which these annual or triennial means are based vary across observations. The second row of the table reports that the means are based on an average of 15 measurements, but there is substantial variability in the number of measurements.

2.2 Explanatory variables

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

⁸A 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 (anywhere along a river anywhere in the world) is infinite and few characteristics are available for the unmonitored places.

Table 2: Means and standard deviations of the data

Variable	Mean	S.D.
Pollution level:		
Mean BOD concentration (mg/l)	8.63	31.40
Number of measurements	15.16	13.47
Influence:		
Downstream station	.763	
Trade intensity if downstream	.020	.023
Upstream station	.239	
Trade intensity if upstream	.088	.079
Border station	.195	
Trade intensity if border	.039	.037
Other determinants:		
Upstream population	1.41	3.72
Population with 20 km (millions)	.0469	.0559
GDP (thousand 1996 dollars)	11.48	6.45
Other openness (percent)	59.13	35.86
Flow (m ³ /sec)	3509	7906
Flow data missing	.23	
Deoxygenation rate (days ⁻¹)	.37	.10

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

As a measure of the importance of the downstream country to the upstream country's economy, I use a bilateral version of the standard openness measure: the ratio of exports plus imports to total GDP. The upstream country must exert control of transboundary pollution, so the relevant measure is the influence of the downstream country on the upstream economy. Thus, the trade intensity measure is the sum of upstream imports from plus exports to the downstream country divided by the upstream country's GDP, although the station may be located in either the upstream or downstream country:

$$\text{Trade_intensity}_{ud} = \frac{\text{Exports}_{ud} + \text{Imports}_{ud}}{\text{GDP}_u},$$

where indices u and d reflect the upstream and downstream country. Robustness checks later in Section 3 vary the trade intensity measure.

Table 2 reports the mean of this trade intensity variable separately for stations that are upstream and downstream of borders and for stations on a border. There are a few reasons for distinguishing trade intensity by upstream and downstream location of the station. 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 variables for both relationships 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. Both countries are polluters and victims, giving rise to a richer set of negotiated solutions and perhaps reducing the need for nonenvironmental linkages. These stations also present a technical problem for the analysis: the trade intensity measure requires selecting an upstream country. To avoid arbitrary assignments, I defined trade intensity for border stations as the average intensity between the two countries.⁹

Table 2 shows that the majority of international stations are downstream of a border. The mean intensity for these stations is 2% of the upstream country's GDP. This value ranges in the data from slightly more than zero to 10%. A higher mean, 9%, characterizes the upstream stations, with a maximum of 23%.

Table 2 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.

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 provides a geographic grid of the direction that water flows in each cell (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.

The upstream population values are noisy because the calculated location of the river (based on flow accumulation) often does not correspond to its actual location.¹⁰ However, these miscalculations do not seem to introduce any systematic bias from the perspective of

⁹The 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.

¹⁰I believe these differences result from insufficiently fine resolution of the Hydro1K flow direction grid.

the current analysis. An alternative approach of manually estimating upstream population by counting upstream cities is difficult for complex river systems, with many tributaries to take into account. It also might introduce bias by overrepresenting population in places with high urban concentration relative to more rural areas.

As an additional and less noisy measure of population, the equations include population within a 20 km of the station, again based on the Gridded Population of the World. These data capture both costs and benefits of control because they include local up and downstream population. I have scaled the 1994 local population by the national population of the reporting country to create a time-varying measure.

National per capita income also 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 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).

As Table 2 reports, income averages over \$11,000 per capita in 1996 dollars. The high value of per capita income results from the greater tendency of higher income countries to participate in GEMS. It also results from the restriction of the sample to international rivers because European rivers are prominent among rivers that cross international borders.

In addition, the equations include a measure of the reporting country’s openness. A country’s general trade climate likely affects bilateral trade with resource partners. If this general climate also affects pollution levels, as previous research on trade and the environment suggests, failure to include a variable reflecting this climate 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. The adjustment is to exclude bilateral trade with resource partners from openness to eliminate collinearity in the construction of the variables.

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

As reported in Table 2, the average openness is high, 59%, reflecting the prominence of European and other geographically small countries in the sample. For stations on borders, it seems arbitrary to select the reporting country's values for the country-level variables, GDP and openness, so the value used in the equations is the mean of the values for the two neighbors.

Finally, variables are included to reflect the effect of a given amount of waste on water quality in the river. First, the river flow determines dilution rates and thus the effect of waste input on in-stream pollution concentrations. Second, rivers vary in the speed of attenuation of pollutants. 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

$$\log b_{it} = g(TI_{it}, POP_i, GDP_{it}, f_i, k_{it}, t) + \epsilon_{it}, \quad (1)$$

where b_{it} is the mean pollution concentration at station i in year t , TI_{it} is the trade intensity measure, POP_{it} is upstream and local population (the latter varying with t), GDP_{it} is annual per capita GDP, f_i is river flow, and k_{it} is the deoxygenation rate. A trend, t , is included to capture changes over time in pollution control technologies and environmental preferences. Some of the equations also include country or station effects.

A log-log functional form was chosen for equation (1) because factors that affect the uncontrolled pollution levels, such as upstream population and river flow, seem likely to have multiplicative effects. There are two exceptions to the log-log specification. GDP variables enter the equation with a quadratic in levels to follow the specifications used in

earlier work. 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 3 reports the results of estimates of equation (1). I will discuss the estimates of the coefficients on the trade measures first, followed by the other covariates.

Trade measures. The first equation in Table 3 does not include country effects. In this equation, the estimated coefficients on bilateral trade are statistically insignificant.¹² The point estimate on intensity at downstream stations has the expected negative sign, but the sign is positive at upstream and border stations.

The second equation in Table 3 adds country effects to account for heterogeneity across countries not captured by the income, population, and river characteristics. However, country effects have the disadvantage that they 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.

With the inclusion of country effects, the point estimate of the coefficient on the inten-

¹²The dummy variables for the upstream, downstream and border location of the station are included to allow the different influence measures to be entered when they do not pertain to all stations. All stations have values of one for at least one of the dummy variables and sometimes several. Thus, these variables should be interpreted as indicating pollution levels relative to other stations on international rivers, but not relative to stations on domestic rivers.

Table 3: Weighted least squares estimates

	Dependent variable: Log (Mean BOD conc.)				
	(1)	(2)	(3)	(4)	(5)
Effects	None	Country	Station	Country	Country
Sample	All	All	All	Non EU	EU
Downstream station	-.202 (.394)	-.105 (.308)	–	-1.53 (.708)	1.412 (1.06)
Log(Trade intensity) if downstream station	-.089 (.112)	-.070 (.069)	-.030 (.068)	-.150 (.065)	.362 (.300)
Upstream station	.551 (.345)	-.954 (.679)	–	.252 (1.04)	.131 (.588)
Log(Trade intensity) if upstream station	.105 (.106)	-.219 (.168)	-.009 (.179)	.156 (.179)	.199 (.231)
Border station	.017 (.518)	-.395 (.323)	–	-.475 (.614)	-4.66 (3.88)
Log(Trade intensity) if border station	.048 (.123)	.157 (.089)	.393 (.163)	.183 (.270)	1.135 (.847)
Log(Upstream population)	.030 (.029)	.029 (.032)	–	-.058 (.021)	.036 (.045)
Log(Population within 20 km)	.101 (.050)	.063 (.050)	1.412 (.740)	.128 (.042)	.029 (.126)
GDP per capita	.130 (.116)	.200 (.094)	.026 (.112)	-.027 (.192)	.038 (.257)
GDP per capita squared	-.006 (.003)	-.008 (.004)	-.003 (.003)	.001 (.010)	-.000 (.007)
Log(Other openness)	.177 (.138)	-.118 (.157)	-.076 (.126)	-.091 (.130)	-.237 (.569)
Log(Flow)	-.243 (.091)	-.156 (.100)	.128 (.056)	.127 (.049)	-.403 (.168)
Flow missing	-1.54 (.825)	-1.02 (.821)	–	2.555 (.509)	-2.34 (.951)
Deoxygenation rate, k	.268 (.851)	.281 (.901)	-.913 (.652)	-1.85 (.754)	6.733 (4.70)
Year	.013 (.016)	.014 (.019)	-.014 (.014)	.016 (.016)	-.076 (.023)
Intercept	.412 (1.82)	–	–	–	–
R ²	.41	.52	.11 (within)	.64	.66
Number of observations:	401	401	401	225	176
Number of stations:	73	73	73	39	34

Notes: Weighted by number of measurements.

Standard errors (in parentheses) robust to clustering at the station level.

sity measure becomes negative at both upstream and downstream stations. However, the coefficients remain individually and jointly statistically insignificant at the 5% level.

There is no evidence of 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.

Column 3 contains estimated coefficients with effects for station-level unobserved heterogeneity, such as local economic activity and river conditions that are not otherwise captured. Negative but substantively very small and statistically insignificant coefficients are estimated on both upstream and downstream trade intensity. The failure to find effects here may not be surprising. Short run fluctuations in trade are unlikely to influence the ability of countries to coordinate.

In column 3, the coefficient on intensity at border stations has a counterintuitive positive and statistically significant sign. A scale effect may explain this positive coefficient. When countries conduct more extensive trade with a neighbor across the river, population and industrial waste may increase near the river, raising uncontrolled pollution levels.

The fourth and fifth equations in Table 3 distinguish observations for stations in EU countries from those in non-EU countries. For non-EU observations (column 4), there is evidence that pollution is lower when countries have extensive trade. The coefficient on trade intensity at downstream stations is statistically significant. The estimated effect is a 1.5% reduction in pollution for a 10% increase (about .3 percentage points at the sample means) in intensity as a share of GDP.

Despite the observed effect at downstream stations, the coefficient on trade intensity at upstream stations is positive and statistically insignificant in the non-EU equation. Since we would expect to observe effects both upstream and downstream of borders, the evidence about trade intensity is somewhat ambiguous even at these non-EU stations.

At stations within the EU (column 5), none of the trade variables enters with a statisti-

cally significant coefficient, nor are the coefficients jointly significant. Trade may have less effect within the EU than outside for several reasons. First, centralized environmental institutions within the EU may make bilateral side payments or threats unnecessary. Second, explicit side payments may be more readily available for countries already cooperating, as the example of chlorine pollution in the Rhine suggests. The results here are consistent with my earlier finding that EU stations exhibit less evidence of free riding than other stations on international rivers.

Other determinants. The results for the remaining variables in Table 3 also depend on the specification and sample. Upstream population is not statistically significant in most equations and even has a negative point estimate for the non-EU sample. Measurement error may contribute to the estimates of this coefficient. The local population measure is statistically significant without country effects and for the non-EU sample, but with a surprisingly low elasticity of pollution to population of about .1. With station effects, only country-level population growth identifies this coefficient. Despite this less direct link to conditions at the station, the elasticity estimate is higher, 1.5, and seems more plausible.

The GDP coefficients follow an inverted U-shaped pattern, but are not jointly statistically significant at 5% except in column 1 (without country or station effects). The coefficient on other openness is not statistically significant at the 5% level in any of the estimated equations. Without country effects, its point estimate is positive, but switches to negative with the inclusion of country effects. The negative point estimate suggests declining pollution with greater trade, which is consistent with most of the empirical literature on this topic.

The coefficient on river flow rate changes sign across equations. It is negative and statistically significant in column 1 and in the EU sample. This coefficient is consistent with greater dilution of pollution in larger rivers. However, it enters with a statistically significant positive coefficient in the column 3 (with station effects) and column 4 (the non-EU sample). Flooding greatly increases BOD, which may account for a positive effect of flow

Table 4: WLS estimates, alternative definitions of trade intensity

	Trade intensity at		
	downstream station	upstream station	border station
Trade intensity = $\frac{\text{Exports}_{\text{ud}}}{\text{GDP}_{\text{u}}}$.074 (.110)	-.225 (.176)	.115 (.085)
Trade intensity = $\text{Exports}_{\text{ud}} + \text{Imports}_{\text{ud}}$.077 (.058)	-.204 (.127)	.137 (.075)
Exclude border stations	-.105 (.072)	-.211 (.178)	–
Intensity only for stations with 100 miles of border	.119 (.067)	-.031 .139	.015 (.095)

Notes: Full equations as in table 3, column 2.

Standard errors (in parentheses) robust to clustering at the station level.

Excluding border stations reduces the sample to 323 observations and 61 stations.

when we look only at time series variation. The difference between the effect of flow at EU and non EU stations is difficult to explain, however. The coefficient on the deoxygenation rate, k , also varies greatly across specifications. A negative coefficient is expected because the variable is a decay rate, but only appears in the non-EU sample.

Finally, the time trend is statistically significant only in Europe. The rate of decline is high, almost 8% a year, suggesting that pollution control regulations in Europe effectively reduced pollution. Elsewhere, however, efforts may have been more limited or less successful.

3.2 Other measures of trade intensity

Table 4 reports the results for different measures of trade intensity. The covariates in the equations are the same as in column 2 of Table 3, but have been suppressed in Table 4.

The first row of Table 4 modifies the definition of trade intensity to depend only on exports

from the upstream country to the downstream country. A common naive view recognizes the producer surplus from exports, but ignores the consumer surplus from imports. Upstream politicians are more likely to respond favorably to offers that increase their exports than their imports. This redefinition does not much change the estimated effect of influence at upstream stations, but the point estimate at downstream station becomes positive although statistically insignificant.

The second row of Table 4 modifies the definition of 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 3. Pollution reduction requires an expenditure for which the upstream country would like to be compensated, so the ability to provide a sufficient absolute sum may be more relevant than the share of GDP. The estimated coefficients are very similar to the coefficients with the earlier intensity 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 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 choose 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 2 of Table 3. Both downstream and upstream influence are negative. Although individually statistically insignificant, they are now jointly significant at the 10% level.

The fourth row of Table 4 addresses the effect of distances to the border. If the mechanism for an influence of trade on pollution is coordination (rather than the scale, composition, or technique effects), this effect should only be seen where pollution spillovers between the

countries play a role. Far upstream of a border, the vast majority of the costs pollution 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 (or lack thereof).

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. By removing cases where trade is less likely to matter, one would expect more negative point estimates here than above. However, the coefficients of interest remain statistically insignificant.

3.3 Endogeneity of bilateral trade

The equations estimated above would 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, a negative coefficient is also consistent with the reverse causality: countries that have achieved environmental coordination expand their trade. If the causality goes this direction, it would still suggest 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.¹³ Thus,

$$TI_{udt} = g(A_u, A_d, P_{ut}, P_{dt}, LL_u, LL_d), \quad (2)$$

where A_u and A_d represent the land area of the upstream and downstream country, and P their population, 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 population measures (upstream population and local population) accurately capture the influence of population and that country-level measures do not add relevant information.

A complication in implementing this strategy is that observations that are not upstream have a zero value for intensity at an upstream station (and similarly for downstream and border locations), so equation (2) does not determine the value of intensity. I sidestep this problem by restricting attention to influence at downstream stations for the IV estimates. Downstream stations were chosen as the focus because they provide the largest sample and the most evidence of a trade effect. Thus, the estimated equations use a subset of observations corresponding to the 60 downstream stations.

Table 6 presents the instrumental variable estimates. The first column in Table 6 repeats the equation in column 2 of Table 3 restricted to downstream stations (and without the border and upstream influence variables) to provide a comparison for the IV estimates. The next column presents the IV estimates for the same equations. The IV approach produces an even smaller negative effect on downstream influence than the OLS equation and the coefficient remains statistically insignificant.

¹³In 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: OLS and instrumental variables estimates

	Dependent variable: Log (Mean BOD conc.)	
	OLS	IV
Log(Trade intensity) if downstream station	-.137 (.085)	-.064 (.130)
Log(Upstream population)	.031 (.035)	.036 (.038)
Log(Population within 20 km)	.143 (.073)	.127 (.078)
GDP per capita	.243 (.122)	.184 (.140)
GDP per capita squared	-.010 (.005)	-.009 (.005)
Log(Other openness)	-.337 (.194)	-.342 (.201)
Log(Flow)	-.302 (.150)	-.297 (.152)
Flow missing	-2.02 (1.12)	-2.00 (1.13)
Deoxygenation rate, k	-.122 (1.16)	-.458 (1.18)
Year	.020 (.021)	.019 (.021)
R ²	.60	.60

Notes: Includes only downstream stations.

Number of observations: 311; Number of stations: 60.

Standard errors (in parentheses) robust to clustering at the station level.

Instruments for influence: Upstream and own country area, upstream country and own country population, and upstream and own landlock status.

Both equations include country effects.

A Hausman test of the OLS specification in column 1 against the IV specification in column 2 fails to reject the OLS specification (chi-squared .32). 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 results show little evidence of a negative association between countries' trade and the pollution of resources they share. A negative effect is observed only at monitoring stations outside the EU and is small, with an elasticity of pollution to trade of only about -.1.

There are several reasons for the lack of an effect. One possibility is the limited available data. Although GEMS is the largest international database on in-stream pollution, only 73 stations allow tests of a trade effect and only 39 stations are outside the EU where the effects of trade on cooperation are most likely.

It is also possible that the underlying effect is indeed small or nonexistent. A small effect would arise if coordination is rare, so most upstream countries chose pollution levels without regard to their downstream neighbors. The very small number of treaties addressing river pollution may support this conclusion. Alternatively, it may be that coordination does occur, but does not require indirect measures such as those supported by trade. Within the EU, formal institutions may obviate the need for specific economic inducements. Both within and outside the EU, explicit side payments may not be that difficult to accomplish, for example, through subsidies offered by the downstream country for installation of pollution control equipment.

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