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 some evidence of lower water pollution in rivers shared between countries with more extensive trade, especially outside the European Union, but the effect is small.

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International trade may facilitate the resolution of transboundary environmental problems. If countries bargain to resolve international spillovers, their agreements may require side payments, but explicit side payments are likely to be difficult politically. Countries with extensive trade may have more opportunities for disguised side payments than countries with limited economic contacts. Similarly, trade relationships may 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.[2] 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. First, they are shared by a small and well-defined group of countries. Thus, it is possible to choose a limited number of bilateral trade values relevant to the resource. Second, a single country may share different rivers with different neighbors, meaning that even within countries cross-sectional variation can help identify the equations. Third, 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. 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 levels, upstream population calculated using a Geographic Information System, and other river characteristics that may affect

[2]The reason for using pollution levels rather than environmental agreements is that countries may have implicit agreements or may sign explicit agreements that do not constrain behavior (Murdoch, Sandler, and Sargent, 1997; Congleton, 1995). For a study of the influence of explicit environmental agreements on water quality in international rivers, see Conte Grande (1997).

pollution levels. I study biochemical oxygen demand (BOD), a common form of pollution for which my earlier research shows evidence of free riding by upstream countries (Sigman, 2001).

The results provide some limited support for the hypothesis that trade facilitates environmental cooperation. The trade intensity measure has a negative effect on pollution in international rivers outside the European Union (EU). However, the effect is empirically small and not especially robust to the specification.

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 effects. Section 4 briefly discusses the implications of the results.

1 Bilateral trade and shared resources

There are several ways that trade between two countries may effect pollution in resources they share. One effect is on the countries' ability to coordinate environmental policies to overcome incentives to free ride. When pollution crosses national borders, polluting countries do not experience the full benefits of their pollution control and may free ride. However, countries that experience the spillover may negotiate with their neighbors and rely on trade to assist in reaching agreement.[3]

Agreements may require side payments from countries that experience damage from the pollution to polluting countries (Mäler, 1990). However, there may be significant limits to these side payments in practice. Most governments are likely to find it politically difficult to make substantial direct payments to other governments or to pollution sources in other

[3]Most of the growing theoretical literature on international environmental agreements focuses on global pollutants, such as greenhouse gases, which differ in important ways from regional and directional pollutant studied here. On the role of side payments and sanctions in the global context, see Hoel, 1992; Carraro and Siniscalco, 1993; Chandler and Tulkins, 1994; and Barrett, 1997 and 2001.

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. 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.

Alternatively, countries may attempt to use sanctions to create incentives for greater provision of shared environmental goods. Again, countries with extensive economic contacts may provide more opportunities for such responses than countries with less contact. U.S. sanctions in the shrimp-turtle and dolphin-tuna cases provide examples of use of trade measures (Vogel, 1995; Chang, 1997), but other threats are also possible.

In addition to these effects of trade on policy coordination, bilateral trade may also effect the uncoordinated equilibrium. As with any trade, 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.[4] The empirical work includes variables 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, if environmental policies are coordinated and vary with exposure, reducing trade frictions moves pollution downstream. 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

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

but also from 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, 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 are inappropriate.[5]

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.[6]

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.

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,

[5]For example, Reppelin-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.

[6]There 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

Table 2: Means and standard deviations of the data

Variable	Mean	S.D.
Pollution level:		
Mean BOD concentration (mg/l)	8.62	31.40
Number of measurements	15.16	13.47
Influence:		
Downstream station	.763	
Trade intensity if downstream	.024	.028
Upstream station	.239	
Trade intensity if upstream	.110	.100
Border station	.195	
Trade intensity if border	.055	.052
Other determinants:		
Upstream population	1.41	3.72
GDP (thousand 1985 dollars)	7.69	4.40
Openness	66.25	46.20
Flow (m^3/sec)	3509	7906
Flow data missing	.23	
Deoxygenation rate ($days^{-1}$)	.37	.10

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 8.5 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 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. Because control of transboundary spillovers must be exercised by the upstream country, the trade intensity measure is calculated based on the upstream country's imports from and exports to the downstream country and upstream GDP, although the station may be located in either the upstream or downstream country. Thus,

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

where indices u and d reflect the upstream and downstream country.

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. The first reason is the complication that 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.

Second, 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.

Third, distinguishing upstream and downstream stations helps address strategic reporting. Upstream countries have an incentive to report cleaner water selectively, but downstream countries have the reverse incentives. We might see a smaller effect of trade upstream if upstream free riding is underreported.

Several of the stations are located on a river when it forms a border between two countries. For these stations, it is difficult to define an intensity measure because both countries are upstream countries to some extent. To avoid arbitrary assignments, I defined trade intensity for border stations as the average intensity between the two countries.[7]

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 13%. A higher mean, 11%, characterizes the upstream stations, with a maximum of 28%.

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.[8]

National per capita income also may affect the costs of pollution control and the benefits of water quality. Summers and Heston's database provides annual income levels standardized for cross-country comparisons (Summers and Heston, 1991).[9] Previous studies have found

[7]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.

[8]I used ArcView's flow accumulation function with cells weighted by their population to calculate these values. The values are very noisy because the calculated location of the river often does not correspond to its actual location. However, these miscalculations do not seem to introduce any systematic bias.

[9]After 1992, Summers and Heston data are not available. I use World Bank income measures to scale the last year of Summers and Heston data to represent later years.

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 almost $8,000 per capita in 1985 dollars. The high value of per capita income results from the greater tendency of higher income countries to report 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.

Table 2 also reports the standard multilateral openness measure, total exports plus total imports divided by GDP, for the country in which the station is located. This variable is included to distinguish the effects of bilateral trade from the more general effects of trade. Again, the average level of this variable is high, 66%, reflecting the prominence of European and other geographically small countries. 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 regression is the mean of the values for the two neighbors.

Finally, variables are included to reflect the effect of a given amount of waste input on water quality in the river. First, the river flow determines dilution rates and thus the effect of a given amount of waste 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

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

where b_{it} is the mean pollution concentration at station i in year t, TI_{it} is the trade intensity measure, POP_i is upstream population, GDP_{it} is annual per capita GDP, f_i is river flow, k_{it} is the deoxygenation rate, and c_i is a country effect. A trend, t, is included to capture changes over time in technology and preferences.

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.

Table 3 reports the results of the estimated equations. I will discuss the estimates of the coefficients on the trade measures first, followed by a discussion of 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 at both upstream and downstream stations.[10] 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. Country effects

[10]The 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)
Country effects?	No	Yes	Yes	Yes	Yes
Sample	All	All	No borders	Non EU	EU
Downstream station	-.311	-.108	-.081	-.949	1.583
	(.343)	(.304)	(.322)	(.747)	(.948)
Log(Trade intensity)	-.112	-.091	-.122	-.144	.422
if downstream station	(.087)	(.067)	(.062)	(.063)	(.279)
Upstream station	.417	-.941	-.843	1.063	.026
	(.343)	(.685)	(.729)	(1.24)	(.558)
Log(Trade intensity)	.079	-.231	-.233	.090	.158
if upstream station	(.113)	(.162)	(.178)	(.221)	(.233)
Border station	.538	.810	–	.795	1.953
	(.531)	(.381)		(.990)	(1.42)
Log(Trade intensity)	.136	.240	–	.232	.763
if border station	(.121)	(.080)		(.237)	(.734)
Log(Upstream population)	.038	.032	.028	-.045	.043
	(.033)	(.033)	(.031)	(.028)	(.048)
GDP per capita	.181	.283	.322	.239	.153
	(.153)	(.127)	(.165)	(.390)	(.314)
GDP per capita squared	-.012	-.014	-.016	-.010	-.005
	(.008)	(.007)	(.009)	(.028)	(.016)
Log(Openness)	.282	-.168	-.153	.158	.246
	(.149)	(.108)	(.166)	(.246)	(.445)
Log(Flow)	-.225	-.134	-.174	.107	-.399
	(.088)	(.095)	(.137)	(.052)	(.165)
Flow missing	-1.51	-.928	-1.13	1.974	-2.30
	(.799)	(.815)	(1.01)	(.546)	(.939)
Deoxygenation rate, k	-.047	.343	.118	-1.61	7.231
	(.674)	(.828)	(.930)	(.830)	(4.71)
Year	.017	.004	.014	.012	-.075
	(.016)	(.017)	(.020)	(.016)	(.026)
Intercept	-.651	–	–	–	–
	(1.90)				
R^2	.41	.52	.54	.64	.66
Number of observations:	401	401	323	225	176
Number of stations:	73	73	61	39	34

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

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

The results do not show any evidence of the special composition effect described in section 1 in which freer trade allows industry to move to the lower reaches of a rivers where exposure is lower. This effect would have given rise to a negative coefficient upstream and a positive coefficient downstream.[11]

The coefficient on intensity at border stations has a counterintuitive positive and statistically significant sign. The location of economic activity may provide an explanation for this positive coefficient. Countries that are oriented toward trade with a neighbor across the river may have industry located near that neighbor and hence near that river, raising uncontrolled pollution levels.

The third equation shows the estimates when the sample excludes border stations. A reason for this restriction is that the intensity measures are more arbitrarily defined for border stations than other stations, given the lack of a clear choice as the upstream country. With border stations excluded, the negative coefficient on intensity at downstream and upstream stations remain individually statistically significant (although the coefficient on intensity at downstream stations is significant at the 10% level). The two intensity coefficients are jointly statistically different than zero.

The coefficients on trade intensity are identified by both differences across stations and time series variation at a single station. At least for short periods, the time series variation

[11]The discussion above also advanced some other hypotheses about the relative magnitudes of the coefficients on intensity at upstream and downstream stations, such as the effects of strategic reporting and downstream mitigation. However, the estimates are not precise enough to have any implications about the relative size of these coefficients.

should not play much role in explaining pollution because short run fluctuations in trade are unlikely to influence the ability of countries to coordinate. To test whether the negative effects in column 3 result from time series variation, I reestimated the equation with fixed effects at the station level. The coefficients on intensity (not shown) are not jointly statistically significant with station fixed effects, suggesting that cross-sectional variation principally explains the results in column 3.

The fourth and fifth equations in Table 3 distinguish observations for stations in EU countries from those in non-EU countries. EU observations account for a large share of the total observations in the data. In column 4, there is evidence that pollution is lower when countries have extensive trade for non-EU observations. The coefficient on trade intensity at downstream stations is statistically significant. The coefficient estimate can be interpreted as an elasticity, so the magnitude of the estimated effect is a 1.4% change in pollution for a 10% change (about .3 percentage points at the sample means) in intensity as a share of GDP.

The coefficients on trade intensity at upstream stations and border stations are positive and statistically insignificant in the non-EU equation. Thus, 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 statistically significant coefficient, nor are the coefficients jointly significant. The small number of observations in the EU sample may account for the difference in results between the EU and non-EU sample. However, it is also possible that trade is indeed not influential in this group of observations. There could be a few reasons for this pattern. First, centralized environmental institutions within the EU may make bilateral side payments or threats unnecessary. Second, explicit side payments may be less of an obstacle within a group of countries that already coordinate public policies. For example, explicit side payments have been used in a program to reduce chlorine pollution in the Rhine River (Bernauer, 1996). 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. Surprisingly, upstream population is not statistically significant at any of the stations and even has a negative point estimate at the non-EU stations. Measurement error may contribute to the lack of a result (see footnote 8). The GDP coefficients follow an inverted U-shaped pattern, but are not jointly statistically significant at 5% in the equations.

The coefficient on overall 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 the empirical literature on this topic.

The river flow rate enters with a negative coefficient, consistent with dilution, in most of the equations. However, this flow coefficient is only statistically significant in the equations without country effects and the EU sample. The deoxygenation rate, k, is never statistically significant and the coefficient varies greatly across specifications.

Finally, the time trend is statistically significant only in the European sample. This estimate suggests that pollution control regulations in Europe effectively reduced pollution, but elsewhere efforts were either more limited or less successful.

4 Conclusion

The results show some evidence of a negative association between trade levels among countries and the pollution of resources shared by them. The effect is small, if it exists, with an elasticity of pollution to trade of only about -.1 The evidence for this relationship is strongest at stations outside the EU. There may be a need to coordinate by threats and side payments outside of the EU, but not within the EU, where other coordination approaches

are available.

However, several caveats are necessary in interpreting these results. First, the results are based on a small and not especially representative set of river monitoring stations. Only about seventy GEMS stations satisfy the requirements for inclusion in the data set. The evidence of trade effects is largely in the approximately half of this sample outside the EU.

Second, the direction of causality is not clear from the analysis. Although one inference is that trade relationships facilitate reaching common environmental goals, the results are also consistent with the reverse causality: countries that have achieved environmental coordination expand their trade relationship. 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 problems.

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