The Costs of Decentralization: Water Quality Spillovers from the Re-drawing of County Boundaries in Brazil

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Abstract

We examine the effect of political decentralization on pollution levels in Brazilian rivers. Upstream water use has spillover effects on downstream jurisdictions; greater decentralization (e.g. a larger number of political jurisdictions managing the same river) may exacerbate these spillovers, as upstream communities have fewer incentives to restrain their members from polluting the river at their borders. We use a panel dataset of over 21,000 water quality measures collected at 795 monitoring stations located in all eight river basins across Brazil and the evolving boundaries of the 5500 counties across Brazil to study (a) whether water quality degrades across jurisdictional boundaries, and (b) whether the splitting of counties (i.e. greater decentralization) is associated with larger deterioration in water quality over time. Boundary crossings are likely correlated with several relevant omitted characteristics of the counties that the river flows through (e.g. population heterogeneity), and we show that these introduce substantial bias in the estimated spillovers. In regressions that only use variation coming from county splits, we find evidence of substantial negative spillovers on downstream jurisdictions which are only partially mitigated by increases in sanitation services brought about by decentralization. An additional county border crossing leads to a 25% larger decline in water quality.

1. Introduction

Water is a publicly provided good of fundamental importance. Over one billion people in the world lack sufficient water, and over 90 percent of sewage and 70 percent of industrial wastes are dumped into surface water untreated (Revenga 2000). Diarrhea, whose incidence is related to the lack of access to clean water, kills 1.3 million children every year and accounts for 12 percent of under-5 mortality (WHO 2003).

The hundreds of international and intra-national conflicts over water sharing throughout history (Wolf 2002) are symptomatic of the microeconomics of water quantity and quality degradation. The flow of rivers creates 'upstream' and 'downstream' regions, and water conflicts are often related to the opening of a diversion gate upstream or the discharge of pollutants into the water as it flows downstream. With these negative spillovers on downstream users, the economics of externalities suggests that in the absence of coordination mechanisms, water use may be 'inefficient' from a societal perspective.

Decentralization initiatives that have been promoted by international organizations and some scholars as a way to improve public service delivery (World Bank 2003, Bardhan 2002) may actually exacerbate cross jurisdictional spillovers once jurisdictions start making unilateral decisions. For example, a reduced role for the central authority in favor of sub-national (e.g. state or county) government management could lead to upstream water policy that promotes over-usage and over-pollution, as costs to downstream communities are not considered during planning processes. On the other hand, if decentralization increases the budgets of local governments or otherwise reallocates resources toward environmental or sanitation spending, it has the potential to improve water quality. These issues are not unique to water quality, and are relevant for any publicly provided good with spillovers. For example, local governments may under-invest in health programs if the positive spillover benefits of improvements in health status (e.g. Miguel and Kremer 2004) to those residing outside the jurisdiction are not taken into account.

This paper empirically examines the effect of decentralized management on negative water quality spillovers on downstream users in Brazil. We use a rich panel dataset of water quality measures collected at monthly intervals at 795 monitoring stations located in all eight major river basins across Brazil to examine (a) whether water quality degrades across jurisdictional boundaries, and (b) whether greater decentralization is associated with greater deterioration in water quality over time.

Rivers and tributaries that cross county boundaries create natural experiments which can be used to study the magnitude of spillovers. We first examine whether there are differentially larger drops in quality at monitoring stations downstream from a county boundary (or more generally, when a river crosses a larger number of jurisdictional boundaries while traversing the same physical distance). The number of boundary crossings is likely correlated with several relevant omitted characteristics of the counties through which the river flows including, among others, the major economic activities in the county, population heterogeneity, and environmental and sanitation spending. We show that these factors introduce substantial bias in the estimated spillover effects. Moreover, some characteristics correlated with both water quality and boundary crossings are not observed in the data and therefore remain “omitted.”

We take advantage of the fact that Brazil has created counties over time (the number of counties increased from 4492 in 1991 to 5562 in 2001), thereby changing the number of boundary crossings for the same river segment as defined by a pair of water quality monitoring stations. This enables us to more precisely identify the effects of decentralization initiatives on the inter-temporal *change* in water quality deterioration by controlling for fixed effects for each station-pair. Since each county has some policy-making authority over environmental regulatory standards and over sanitation spending, the splitting of counties leads to *de facto* decentralization in the sense that more separate jurisdictions gain control over water quality in a river segment.

We find evidence of substantial negative spillovers on downstream jurisdictions which are only partially mitigated by the increases in per-capita sanitation service provision brought about by decentralization. The station-pair fixed effects regressions indicate that the standard McClelland (1974) 100-point index of water quality that we use in our empirical analysis drops by an additional 4.2 points from an upstream to a downstream station when a county split leads to one additional border crossing for that river segment. The average drop in water quality from upstream to downstream stations in our sample is 16.6 points, so each additional border crossing represents a 25 percent greater deterioration in water quality at the mean. A five point drop in the index represents a meaningful change in water quality. Such a decrease in an area which already had marginal water quality may reduce the potential for sustained aquatic life in the river and have health impacts on surrounding communities.

The aggregate effect of decentralization is thus a highly significant degradation of water quality, which implies that the negative spillover effects tend to dominate any offsetting positive benefits through the increase in per-capita health and sanitation spending that may accompany decentralization initiatives. To further examine this trade-off, we net out the positive benefits by directly controlling for the provision of sanitation services in the county, and find that in this specification, the negative spillover effects of decentralization (i.e. additional country boundary crossings) are even larger at 5.0 water quality index points.

2. Related Literature

The decentralization debate has been central to the development community. At issue is the balancing of the objective of improving the accountability and responsiveness of the public sector through decentralization with the difficulty of provision of cross-jurisdiction public goods. The largest development organizations have policies encouraging decentralization. The UNDP's Decentralized Governance Program works with governments to support the empowerment of local governments. The FAO has a policy of prioritizing work with local governments and encouraging rural and local governments to take a leading role in their projects. The World Bank has supported decentralization through loans aimed at policy reform and localization, technical assistance based on local capacity building, and budget analysis of the inter-governmental transfers necessary for decentralization to be successful. Despite these efforts, the debate over the conditions required for decentralization to improve the efficiency of the public sector remains a key issue for development policy makers.

The contribution of the economics literature to the decentralization debate has been primarily theoretical. Seminal to the debate is the work of Oates (1972) in which he points out that decentralization improves efficiency if it enables communities to take advantage of the variation in their preferences for the level of public goods provision. However, Oates (2001) also shows that there are two major sources of inefficiency in decentralization: decentralization allows communities to ignore the externalities that they impose on other regions and causes duplication in management bureaucracy.

As decentralization leads to more accurate targeting of local needs but also reduces incentives to control externalities affecting neighboring communities, the literature examines whether communities are likely to allow excess pollution beyond levels which would be set by a central planning commission. List and Mason (2001) show that decentralization will be more efficient than a centralized government setting uniform standards for pollution as long as spillovers are not too high. Uniform pollution standards are equivalent to a common shadow price of polluting across jurisdictions, but the true marginal cost of added pollution to a locality may be far different than the shadow price set by the central government; therefore there are high returns in decentralization when local governments can set their own standards. Coate and Beseley (2000), by contrast, note that when the budget is shared between localities and there is heterogeneity in preferences within communities, the optimal allocation of the public good need not be reached.

The environmental "race to the bottom" debate has mirrored the decentralization debate. While authors such as Cumberland (1981) have argued that as a result of competition between jurisdictions to attract business investment there will be a "race to the bottom" in environmental quality between jurisdictions, Oates (2001) suggests that a "race to the bottom" is an unlikely result of inter-jurisdictional competition;

environmental damage will be capitalized into local property values, and as a result community members face the implicit shadow price of environmental damage even as they perceive the benefits of increased economic activity in their region.

The policy-making community has noted the relative paucity of empirical evidence for the various arguments in favor of and against decentralization (World Development Report 2000). This lack of empirical evidence is in part due to the difficulty of measuring externalities and in part a result of the impossibility of isolating the effect of decentralization when it is combined with a series of legislative reforms. Our paper contributes to the decentralization literature by taking advantage of the natural experiment afforded by pollution spillovers in the rivers in Brazil over time as decentralization takes place in the form of the creation of additional counties. This natural experiment allows us to isolate the effect of adding additional county borders on pollution levels in the rivers, thereby allowing us to establish causality as we are able to control for non-time varying characteristics in each location.

Community characteristics and ethnic heterogeneity are found to matter in the effectiveness of local decentralization. Foster and Rosenzweig (2002) find that an increase in the percentage of the population which is poor results in an increase in public spending on public goods preferred by the poor, but that fiscal decentralization results in regressive taxation. Bardhan (2000) finds that social homogeneity increases the level of cooperation among farmers in the provision of irrigation while inequality decreases the level of cooperation. We further test the importance of homogeneity by measuring the impact of heterogeneity in community characteristics on the pollution spillovers: we find that local heterogeneity does increase pollution spillovers.[1]

Sigman (2002) provides some initial tests of the allocation of externalities across jurisdictional boundaries. Sigman tests the existence of pollution spillovers in rivers across international borders. She looks at pollution levels in rivers for a period spanning 1979-1996 over 49 countries. She finds that stations just upstream of borders have higher levels of biochemical oxygen demand (BOD) than similar stations elsewhere. However, she finds that the effect changes sign when she adds country fixed effects, although it is not statistically significant. The exclusion of fixed effects by country could lead to substantial omitted variable bias; there are a variety of institutional, geographic, community, and economic factors which are omitted that are likely to be correlated with water quality, thereby biasing the coefficient of interest. Even within a country, there may be large variation in these factors which could create omitted variable bias. By including fixed effects by monitoring station one could reduce the bias from non-time varying unobservable factors.

Sigman (2005) analyzes the effects of spillovers in the US following the Clean Water Act. She uses variation in the time at which states were authorized to enforce the Clean Water Act within their boundaries in order to determine the impact of the decentralization of control over water policy. She finds evidence of spillovers by states which have received control over their water policies. Her estimation technique is based on whether a monitoring station is upstream, downstream, or bordering a state. She finds that a significant number of stations are categorized in more than one group. This

[1] Lacking panel data on community heterogeneity measures, we are unfortunately unable to measure the magnitude of this effect.

problem could lead to significant identification error as many upstream stations are also considered downstream stations. In addition, she uses a 50 mile perimeter of the border to identify stations as close to the border.

We use several methods of improving the accuracy of identification. First, we use differences in water quality between a downstream station and the first upstream station above it. This reduces confusion over whether a station should be characterized as “upstream” or “downstream.” In addition, because we take advantage of the changes in county boundaries in Brazil over time, we are able to use the actual distance to both the upstream and downstream border in our regressions. By doing so, we are able to identify the effect of being an additional kilometer from the border, as we expect the upstream county to pollute most close to its downstream border. We expect attenuation in the downstream county as the downstream county has an incentive to be more vigilant in deterring pollution. In addition, we include fixed effects for each station pair in order to control for unobserved non-time varying factors such as ethnic heterogeneity, geographic factors, and economic activity.

3. Background

Brazil’s federal nature and the large variation in climates across its vast territory have meant that each region in Brazil has had a different experience with managing their water resources. States have devolved control over water management at different rates, and have encouraged varying levels of participation by civil society. Several case studies have analyzed the decentralization of water policy in specific regions of Brazil. Brannstrom (2004) considers the policies Brazilian states have used in the course of decentralization of water management. He finds that policies which have encouraged interaction between all levels of government and the communities have been the most successful in controlling water resources. Formiga-Johnsson and Kemper (2005) analyze the management of the Alto-Tiete river basin, and find important successes in implementing water reforms related to the growth in inter-county water management committee participation. They find that local sub-basin groups have increased cooperation as a result of the participatory reforms, and water use initiatives have been most successful at the most local levels. The results of this paper indicate that such inter-county management groups could be important in enabling counties to negotiate for a reduction in the externalities imposed on them by their upstream neighbors.

A. Can Counties Affect Water Quality?

Although general environmental policy setting and enforcement is determined at the national and state levels, counties in Brazil have important powers over practices affecting the environment within their jurisdiction. Federal law establishes guidelines, norms, and minimum standards of environmental policy, but the importance of county government participation in environmental policy making has been continually acknowledged by both state and federal law since the 1977 Federal Water Law first established the principle of local participation in water quality management. The Federal Constitution empowers counties to pass laws complementary to federal and state laws, to establish local environmental standards, and to enforce standards within their jurisdiction. While county governments cannot institute standards lower than those passed by the state and federal government, they may enforce norms that are more strict (Engenharia and Projetos 2006).

Local management of natural resources has taken many forms. The importance local governments assign to environmental policy can be seen through how they establish management tools for the negotiation of environmental policy. Below is a summary of environmental management methods employed by the 5,560 counties in Brazil examined in this study.

Administrative Management of the Environment

Counties which have a ministry held responsible for environmental management	3769
Counties which have an environmental management council	1895
Counties in which civil participation in the environment management council is at least 50%	1456
Counties which have technical agreements with the Federal government for environmental management	700
Counties which have technical agreements with the State government for environmental management	1505
Counties which have technical agreements with other counties for environmental management	243
Counties explicitly designated as leaders in environmental management policy	401
Counties belonging to inter-county water quality associations	396
Counties belonging to inter-county environmental management associations	603
Counties with funds dedicated to environmental management	987
Counties with legislation on environmental management	2363

*Counts are as of 2002. There were 5,560 counties in Brazil in 2002. Source: IBGE.

Lack of sewage treatment is the most important source of water pollution across the densely populated areas of Brazil. Approximately 18 percent of counties report having open sewers which flood into major water systems. Farm runoff is the most important cause of water pollution in rural areas of Brazil. Industrial dumping is also highlighted as a significant concern in approximately 10 percent of counties.

County-Reported Causes of Water Pollution

Mining	235
Oil and gas from boats	81
Animal Waste	832
Materials from the Processing of Sugar	160
Industrial Dumping	521
Domestic Sewage	1595
Poor Solid Waste Management	821
Poor enforcement of river pollution regulations	648
Poor enforcement of underground water rights licensing	228
Use of Pesticides and Fertilizers	901
Others	160
Total Counties reporting Water Pollution	2121

*Counts are as of 2002. There were 5,560 counties in Brazil in 2002. Source: IBGE

The federal government turned responsibility for sanitation services over to state governments during the 1970s. In the process of decentralization, states have allocated some authority over sanitation services to county governments. County governments have an important role in determining which areas to extend sanitation services to in peripheral regions that lack access to the sewer network. County governments also have the authority to either choose to continue publicly provided sanitation services through licensing them to the state sanitation agencies which are now privatized, or to implement their own sewage systems (Faria da Costa 2006).

Counties are able to fine and tax their community members for activities which cause pollution. In addition, they are able to forbid highly polluting practices and use zoning regulations to reduce direct runoff. They also manage programs for trash collection and sewage treatment.

County Actions to Reduce Pollution

Fining Households with Inadequate Sewer Systems	2462
Fining Companies with Inadequate Industrial Waste Management Systems	1007
Monitoring of Potentially Polluting Industrial Activities	596

Taxing Mining Industries	1027
Taxing Automobiles	104
Management of Toxic Waste	483
Trash Collection Program	1654
Recycling Program	1082
Creation of Sewers	1949
Other	564

*Counts are as of 2002. There were 5,560 counties in Brazil in 2002. Source: IBGE.

The counties of Quatis and Barra Mansa in the state of Rio de Janero provide an example of the externalities we are considering; a map is provided in Figure 1. Quatis was a district of Barra Mansa until 1991, but was recognized as a separate municipality by state law in September of 1991. Because the river segment between station A and station B traversed the middle of Barra Mansa until 1991, Barra Mansa county incurred most of the impact of pollution from within that region. Pollution added to the water between the stations would pollute the river through the rest of the county, decreasing the available clean water to the citizens downstream. However, when Quatis was recognized in 1991 as a separate county, the border crossed the river downstream of station A. Subsequently Quatis had less incentive to regulate pollution just upstream of point x, because citizens of Quatis were not affected by this pollution. Pollution entering the river at this point flows into Barra Mansa.

Following the spillovers logic, we would expect to see a larger degradation in water quality between station A and station B after the split of Quatis from Barra Mansa. As a result, the water quality index at station B is expected to be lower than it would have been before the county split, and the difference between water quality at B and water quality at A (which is our dependent variable) is expected to become more negative.

B. The Process of Creating New Counties

Brazil created a large number of new counties by splitting larger counties during each election cycle in the 1990s after the power to form new counties was devolved from the federal government to the state governments in the 1988 Federal Constitution. The reasons for creating new counties vary, but polls of mayors of new counties have highlighted the importance of disagreements over the amount of municipal funds used in the districts of the original county, differences in economic activity across districts, and the large size of the original county (Bremaeker 1992). Other research suggests that the split can occur for purely administrative reasons and in order to better represent the political affiliation of the district which leaves the original county (de Noronha 1995). To the extent that counties have policy-making authority over any publicly provided good, the creation of new counties is a form of decentralization in the delivery of that public good (e.g. two smaller governments rather than one larger one are supplying the service to the same population).

Although the process of creating new counties varies across states, its form is similar. The process begins with a feasibility study on the projected solvency of the potential county and a motion for a referendum on the proposal in the state legislature. Both the district newly acquiring county status and the county being split must ratify the proposal in a referendum. The referendums are followed by a state law passed by the state legislature and signed by the governor (Tomio 2002).

Fiscal decentralization accompanied political decentralization in the 1988 constitution, and counties receive transfers from both the federal and the state governments. As a result, incentives to create new counties are high. In addition to a portion of the income and industrial taxes collected in their jurisdiction, counties receive the Municipalities' Participation Fund (FPM). The amount transferred through the FPM is determined by population with 18 set steps, and the lowest amount is awarded to municipalities with less than 10,188 citizens. In response to the proliferation of new small municipalities, in 1996 a federal law was passed setting quotas for FPM by state. This reduced the incentives for state governments to create new municipalities, but local organizers continue to form new counties (Tomio 2002).

There are several possibilities for endogeneity problems related to the creation of new counties which could bias our estimates. First, high population density in certain districts may be one reason that a district decides to separate from its county and form a new county. If high population density also causes increased degradation in water quality, then there would be an omitted variable bias in an estimation run without population density controls. We include population density controls for the upstream county, the downstream county, and the average density for intermediate counties in the case of river fixed effects estimation for this reason.

A second possibility for omitted variable bias would be that if there were significant race, ethnic, or wealth differences between the separating district and the districts remaining in the county, this could decrease the level of cooperation between the communities and result in higher levels of pollution across the border. Several papers, including Alesina, Baqir, Easterly (1999), have shown that public goods are more difficult to provide when there are high levels of heterogeneity in a community. These difficulties could be magnified across district borders. If heterogeneity among districts reduces enforcement of pollution regulations at borders and increases incentives for a district to form a new county, then there could be an omitted variable bias in the estimation.

A further argument for endogeneity would be that counties with strong leadership or community involvement across districts are less likely to have districts separating and forming new counties. Counties with strong leadership may also be more successful in planning and enforcement of pollution policies. This would create a bias on the border crossings coefficient in the negative direction (lower numbers of border crossings imply better water quality).

The possibility of wealth disparities between the separating district and the remaining districts causes the additional concern that one district may have been financing public works programs in the other districts of the county. Without the tax revenues from the separating district, certain public works programs may receive decreased levels of funding, and in many cases these could be pollution abatement and enforcement activities. This would decrease water quality, and again cause a negative bias in the coefficient on the border crossings variable. However, both the separating district and the remaining districts in a county must ratify a proposal for creating a new county in a given district, which means that a wealthy district can not unilaterally decide to become a new county. Because the remaining districts would expect significant decreases in county revenue if they were to allow a wealthy district to separate, it would be rare to see wealthy districts allowed to separate from the county to which they belong.

In section six we present instrumental variables estimates and demonstrate that our results are robust to the use of a variety of instruments for municipal splits.

4. Data

Our unbalanced panel is comprised of water quality measures taken at 795 monitoring stations across Brazil in monthly intervals between 1975 and 2004, which results in over 21,000 individual observations at 890 upstream-downstream station pairs.[2] We exploit two important dimensions of the data. First, through natural variations in geography, in distances between pairs of monitoring stations, and in the placement of stations relative to county borders, there is heterogeneity in whether and how often a river crosses jurisdictional boundaries while flowing from an upstream to a downstream monitoring station (see Figures 2 and 3). This creates cross-sectional variation in the frequency of border crossings for a river segment flowing between a pair of stations. Second, due to redistricting and the redefinition of county boundaries during each election cycle, the number of border crossings for the same river segment between the same pair of stations can change over time. Together, these two dimensions of the data lead to panel variation in border crossings (corresponding to a change in the extent of decentralization for a particular segment of a river), which, coupled with panel data on water quality, can be used to measure its impacts on changes in water quality across space and over time.

Using Geographic Information Systems (GIS) modeling, we measure changes in pollution levels along rivers across geographic space as the river flows from an upstream water quality monitoring station to a downstream station, and catalog the number of jurisdictional (e.g. county or *municipio*) boundaries the river crosses, distances traversed in each jurisdiction, a variety of political, economic, demographic and budgetary

[2] There are 890 station pairs, but only 795 monitoring stations, because each water quality monitoring station occurring on an outermost branch of the river connects to a first monitoring station on the main branch—this means that the same station may be an element of several different station-pairs.

characteristics of each jurisdiction, and other aquatic conditions such as elevation, pollution attenuation and dilution through tributary inflows in addition to region, climate and seasonal controls.

Brazil has re-drawn county boundaries three times between 1991 and 2001, which implies that each water quality observation for a station falls into one of four different county boundary regimes. The number of counties in Brazil has increased from 4492 in 1991 to 5562 in 2001. We merge digital maps of water monitoring stations, rivers, elevation and flow vectors, and the four different county boundary definitions in order to (a) identify the direction of water flow between each pair of stations (to classify them as upstream or downstream), (b) define river segments between station pairs, (c) identify the counties crossed by each river segment, and (d) measure distances traversed within each of those counties.

Using data on effluent levels and oxygen demand from 795 water quality monitoring stations, we build a water quality index based on McClelland (1974). The index integrates data collected on dissolved oxygen, fecal coliform, pH, 5 day biochemical oxygen demand, nitrates, and total phosphates. By averaging the effects of each of these pollutants on water quality, the index integrates information on effluents caused by sewage, agricultural runoff, and industrial dumping. Each of the effluents has a non-linear impact on the overall quality of the water, so the data is transformed into effluent specific quality values and the index is a weighted average of these terms. The range of the index is from 0 (extremely poor) to 100 (pristine). The summary statistics for the water quality index are reported in table 1. Water with a quality index between 91 and 100 is considered of excellent quality. This would be expected primarily near springs and in secluded forest areas. Water with a quality index of between 71 and 90 is considered very good and can support a wide diversity of aquatic life. Average water quality in US rivers is currently about 75. Water between 51 and 70 is of medium to average quality, but can still sustain aquatic life. Index values between 26 and 50 are considered fair quality, able to sustain a more limited set of aquatic life, and pollution may be an issue in these areas. Values between 0 and 26 indicate poor water quality, and direct contact with water in these areas is discouraged in the US. Little aquatic life can be sustained with such high levels of pollution.

Our regressions use each upstream-downstream station pair (or equivalently, the river segment in between) as the unit of observation, and the dependent variable measures the change in water quality from the upstream to the downstream station ($WQI_d - WQI_u$). The dependent variable is therefore measured as a 'geographic difference' (in water quality as the water flows downstream). We explain this change in water quality as a function of some time-varying characteristics of the upstream location and the downstream location (e.g. population density, GDP per capita, public budgets and spending in the counties where the upstream and downstream monitoring stations are located), year, month, season and climatic region effects, and either station-pair fixed effects in panel data regressions or some fixed characteristics of the station pair (e.g. distance, elevation) in pooled cross-sectional regressions. We typically expect upstream and downstream county characteristics to have opposite effects on the change in water quality. For example, an increase in sanitation services downstream should lead to a more positive change in water quality measures from upstream to downstream ($WQI_d - WQI_u$ increases), but holding constant downstream sanitation services, an increase in sanitation service provision upstream should improve WQI_u, thereby decreasing (WQI_d – WQI_u).

The primary variable of interest is the number of county border crossings for the river segment. If pollution spillovers across jurisdictional boundaries are present, then we expect water quality to deteriorate more if the river segment traverses a larger number of counties (i.e. crosses borders more often).

Our set of independent variables also includes the distance traversed in the county where the upstream monitoring station is located (segment A1 in figure 4, between point A where the upstream water quality measures are recorded and point 1 where the river exits that county), and the distance traversed in the downstream county where the second monitoring station is located (segment 2B from the point of entry into the county to the point where the downstream water quality measures are recorded). In the presence of spillovers and pollution externalities that are internalized within a political jurisdiction but not across jurisdictions, WQI_u should increase with the distance traversed within the upstream county (which decreases WQI_d – WQI_u), while WQI_d should increase with distance traversed within the downstream county (which increases WQI_d – WQI_u). This is because near the county border a county may be more likely to free ride by allowing more pollution heavy industries, or by investing less in pollution abatement activities.

We use GIS modeling to calculate the distance the river travels along county borders. Following the above free-riding line of analysis, we would expect counties which have border rivers to strategically invest less in cleaning the river, because they only perceive the effects of the pollution on one bank of the river. We separate this effect by upstream border distance, downstream border distance, and in the case of river group fixed effects, intermediate border distance.

The attenuation rate of pollution differs between station pairs, and has the potential to bias the results as geographical river characteristics may be similar in certain areas where municipalities are smaller and boundaries are more frequently crossed by the river. The bias would occur as systematic higher attenuation rates in certain areas would bias downward the dependent water quality difference index.

Pollution attenuation on a particular river occurs as a function of distance, rainfall, flow rate, water depth, elevation, and river gradient. We use GIS modeling in order to measure distance along the river between stations (in most cases this is larger than straight-line distance as the rivers rarely run directly between two points). In order to proxy for rainfall, we include dummies for seasons in each of the five major regions of Brazil. This is necessary, since seasons vary across Brazil because of its size. We estimate flow rate, water depth, elevation, and river gradient for each station using GIS modeling and map data provided by the USGS. Each of these geographic variables is included as a control in the river fixed effects estimation: flow rate, water depth, elevation, and river gradient are used as controls for both the upstream and the downstream station.

We also use panel data for population density and GDP (as a proxy for economic activity) in each municipality as controls, as these factors are expected to have a strong effect on water quality. Population density is expected to decrease water quality as there is more sewage and urban runoff as population density increases, while economic activity could affect the water quality in either direction: water quality is a normal good, therefore higher GDP may imply a higher water quality index, but economic activity may also imply greater incidence of industrial waste which may tend to degrade water quality. In addition to controlling for the population density and GDP in the municipalities of the upstream and downstream monitoring stations, we average the population and GDP levels for all municipalities which occur along the river between the upstream and downstream stations as these municipalities also face incentives to pollute or to participate in pollution abatement programs.

5. Empirical Identification

To find the effects of additional municipal borders on water quality, we begin by running the regression with fixed effects by river group; here we find evidence of considerable omitted variable bias. To control for omitted variable bias, we then run the regressions with fixed effects by station pair. River fixed effects estimation gives the data a cross-sectional nature as the border crossings coefficient is identified through both variation in the number of borders between stations and variation in the number of borders between stations across time.

The river fixed effects regression is estimated according to the following equation where X is a vector of the standard geographic, population, and GDP controls, and river, month, and year fixed effects as explained above:

$$\Delta WQI_{stp,t} = \beta_0 + \beta_1 municount_{stp,t} + \beta_2 upstrmdist + \beta_3 dwnstrmdist + \beta_4 X_{stp,t} + \varepsilon_{stp,t}$$

Municount is the border crossings variable, so β_1 is the primary coefficient of interest. Results are presented in Table 2. The border crossings variable in this case has a small positive coefficient which is counter-intuitive. However, because the rivers in the data are extremely long and flow through highly varied areas, we find that this coefficient has been biased by omitted variables. Variables affecting water quality between a given station pair are not controlled for, but may affect both water quality and the number of borders in a given region, thereby biasing β_1.

To test whether our river fixed effects regression suffers from omitted variable bias, we estimate the equation again including various controls. We consistently find evidence that the coefficient on the border crossings variable has been biased. We use various different control variables including: the Gini coefficient, urban share of the population, ethnic fractionalization, primary economic activity, health spending, and water services provided by the county. We include each control variable for the observation in the upstream station's county, the downstream station's county, and an average of the values for all counties between the counties in which the water quality stations occur. The bias results from the fact that the control variables affect both the water quality between two counties and the number of county boundaries drawn in a region between the two stations, thereby biasing the coefficient of interest in the positive direction.

$$\Delta WQI_{stp,t} = \beta_0 + \beta_1 municount_{stp,t} + \beta_2 dist_U + \beta_3 dist_D + \beta_4 gini_D + \beta_5 gini_{Int(ave)} + \beta_6 gini_U + \beta_7 X_{stp,t} + \varepsilon_{stp,t}$$

The effect on the coefficient on the number of borders crossed is shown in Table 3. The coefficient on the border crossings variable becomes smaller and less significant in each case, which suggests that omitted variables have created an important bias in our river fixed effects regression.

Because the rivers in our data cover a large amount of territory and extend between regions with varied economic and social activity, the fixed effects by river regressions are unable to control for enough of the joint variation between county borders and water quality which is determined by variation in omitted variables such as land use, ethnic heterogeneity, regional commerce, religion, and inequality. As can be seen in Table 3, regions in which fishing and forestry are the primary activities are characterized by improved water quality. Regions in which agriculture is the primary activity are characterized by reduced water quality, as would be expected as a result of agricultural runoff. In addition, these areas are regions in which new municipal boundaries are less likely to be drawn. Therefore, omitting these variables creates correlation between the independent variables and the error term, forcing positive a bias in the estimate of the coefficient on border crossings.

We run several more regressions to test for additional omitted variables. We find that industry type, ethnic heterogeneity, and urban and rural population densities also have a positive bias on the county boundary coefficient. The effect on the coefficient of interest of including these control variables is shown in table 4.

In order to control for all non-time varying potential sources of bias between stations, we run the regression using station-pair fixed effects (see table 5). We find that the border crossings coefficient is now negative and significant at the 1% level. The size of the coefficient on municount (border crossings) is large, with a 4.2 point drop in the difference between upstream and downstream water quality when an additional county border is crossed. This is a 25% difference at the mean, and a significant decrease in water quality in the downstream county.

We also find that the coefficient on the distance traveled in the upstream county is highly significant and has the expected sign. Upstream counties are unlikely to pollute near a station which occurs well within its borders, but they are likely to allow more pollution closer to its border. Therefore, the farther a water quality monitoring station is from a border, or the higher the upstream county distance variable, the more we would expect the water quality index to increase in the upstream community, decreasing the dependent variable (since the upstream WQI enters negatively). As a result, the coefficient is negative. We find that the coefficient is significant at a 1% level. It is estimated that an additional kilometer traveled from the border in the upstream county results in, on average, a decrease in the dependent variable of .126 index points.

Conversely, we would expect a county to enforce pollution policies most strongly at its upstream border. Therefore, the river has some attenuation of pollution as it travels to the station in the downstream community. The farther the river travels in the downstream community before reaching the downstream station, the larger the expected attenuation effect will be. Here we find limited evidence that this occurs as the estimated coefficient is positive, but it is not significant, so there is high variation in this effect across counties.

Counties which have increased spending in sanitation as a result of their improved control over local spending have seen some reduction in this effect: the size of the coefficient increases from 4.0 to 4.5 (on the restricted sample of counties for which trash collection data is available) when trash collection services have been added to the regression. This represents a 12.5% increase in the size of the coefficient. This suggests that downstream municipalities do have some power to reduce the effects of the spillovers within their borders by abatement and clean-up activities, however, the coefficient while positive for the downstream county is not significant: there is a much stronger effect on water quality when the upstream county has sanitation services. The effect is of magnitude .204, so for a 5% increase in provision of sanitation services, there is a 1 point increase in the water quality index. This is significant at the 1% level.

6. Robustness

We check the robustness of our results by addressing two key measurement concerns. First, it is possible that there would be strategic addition of monitoring stations by counties that were concerned about being polluted on by their new neighbors. This would create a bias in our estimation, and therefore must be addressed. Table 8 shows the estimations done only for the stations which were created before 1989 and 1992 respectively, therefore those that were already in existence at the beginning of our sample. The first column shows the regression results on the entire sample. We find that the magnitude of the coefficient on border crossings is larger in the 1989 and 1992 samples, suggesting that if the counties are strategically placing new monitoring stations, then they are also successful at controlling the added pollution spillovers, thereby biasing the coefficient on our border crossings variable toward 0.

Another potential concern is that counties concerned about the pollution caused by new counties would place their water quality monitoring stations close to the border in order to better measure the pollution spillovers of their new neighbors. Here we run the regressions using only the counties within set distances of the border. In table 9 we present the estimations done using only stations within set distances of the border. If a bias resulting from strategic placement of monitoring stations were to occur, we would expect that stations closest to the border would have the coefficient with the largest magnitude. Here the coefficient on border crossings for the stations within a kilometer of the upstream border is not significantly different from 0. The coefficient for the stations within 5 and 10 kilometers from the border are also smaller than the coefficient on the sample as a whole. Therefore we do not believe that there is a negative bias on our coefficient from strategic placement of the monitoring stations.

7. Conclusion

This paper provides evidence of degradation in water quality where decentralization has occurred. We find significant pollution spillovers between counties. The spillovers are large: an additional county boundary results in a reduction in water quality of 4.2 index points; a reduction of 25% in quality at the mean. This suggests that there is some free-riding between counties: counties are likely to provide stronger enforcement of water quality standards and better and more expensive methods of abatement where their constituents are more likely to be affected by the pollution. Because counties are more likely to allow pollution near their downstream border, a higher incidence of county borders created during the period of high decentralization has resulted in greater degradation in water quality. Consistent with this free riding story are the estimated coefficient signs on the upstream distance and downstream distance variables in the station pair fixed effects regressions.

We find that a county's efforts at pollution abatement can decrease the impact of these spillovers, but that the effect is relatively small in comparison to the size of the spillovers. The negative coefficient estimate for upstream sanitation spending in the station pair fixed effects regressions suggests that increased sanitation spending by upstream communities has a strong influence on water quality. This implies that there could be important gains made through cooperation between upstream and downstream communities through negotiation and transfers. Strategic cooperation among counties in pollution abatement is a potentially interesting avenue for future research.

We also demonstrate that the levels of pollution spillovers are correlated with land use and population heterogeneity in the counties crossed by the rivers. In running river group fixed effects estimations, we find significant omitted variable bias in the coefficient for the number of county boundaries crossed. This bias decreases when controls for various time-invariant region specific characteristics are added. Finally, we perform several robustness checks to demonstrate that our estimated effect is not the result of strategic placement of monitoring stations by the county governments.

References

Agencia Nacional de Aguas (2002). *The Evolution of the Organization and Implementation of Water Basin Management in Brazil*, Report prepared by ANA, Brasilia for the 'International Conference of Water Basin Agencies, Madrid, 4-6 November, 2002.

Alesina, Alberto, Reza Baquir and William Easterly (1999). "Public Goods and Ethnic Divisions," *Quarterly Journal of Economics,* Vol CXIV Issue 4 p. 1243-1284.

Arrow, Kenneth (1971). "Political and Economic Evaluation of Social Effects and Externalities," pp. 3-23 in M.D. Intriligator (ed.), *Frontiers of Quantitative Economics*, North Holland.

Bardhan, Pranab, (2000) "Irrigation and Cooperation: an Empirical Analysis of 48 Irrigation Communities in South India." *Economic Development and Cultural Change.*

Bardhan, Pranab and Dilip Mookherjee, (2000) "Corruption and Decentralization of Infrastructure Delivery in Developing Countries," Working paper, University of California, Berkeley.

Beseley, Timothy and Stephen Coate, (2000), "Centralized versus Decentralized Provision of Local Public Goods: A Political Economy Analysis" CEPR Discussion Paper No. 2495.

Biswas, Asit K. and Cecilia Tortajada (eds.) (2001). *Integrated River Basin Management: The Latin American Experience*, Oxford University Press, New Delhi.

Bowles, Samuel (2003). "Microeconomics: Behavior, Institutions and Evolution," Princeton University Press, Princeton NJ.

Brannstrom, Christian, (2004), "Decentralizing Water Resources Management in Brazil," *The European Journal of Development Research*, Vol.16 Issue 1 pp. 214-234.

Bremaeker, Francois (1992). "Os Novos Municipios: Surgimento, problemas e Solucoes." *Revista de Administracao Municipal*, 40 (206) 88-99.

Cumberland, John H. (1981) "Efficiency and Equity in Interregional Environmental Management," *Review of Regional Studies* 2, pp. 1-9.

Engenharia & Projetos (2006). " Manual de Saneamento e Proteção Ambiental para os Municípios." Monte Santa de Minas, MG.

Epple, Dennis and Allan Zelenitz (1981) "The Implications of Competition among Jurisdictions: Does Tiebout Need Politics?" *The Journal of Political Economy* Vol.89, No.6 pp. 1197-1217.

Faria da Costa, Antônio José (2006). "Saneamento Ambiental," *DICAS: Idéias para a ação municipal.* http://www.federativo.bndes.gov.br/dicas/D121%20-%20Saneamento%20ambiental.htm, last viewed 4/27/06.

Finatec (2003). *Projeto Marca D'Agua: Seguindo as Mudancas Na Gestao Das Bacias Hidrograficas do Brasil*, www.marcadagua.org.br.

Foster, Andrew and Mark Rosenzweig (2002), "Democratization, Decentralization and the Distribution of Local Public Goods in a Poor Rural Economy," mimeo, Brown University.

Grossman, G. and E. Helpman (2001). *Special Interest Politics*. MIT Press. Cambridge, MA.

IBGE (2002). *Perfil dos Municipios Brasilieros*, Meio Ambiente.

Kremer, M. and Edward Miguel (2004). "Worms: Identifying Impacts on Education and Health in the Presence of Treatment Externalities" *Econometrica* 72, No. 1.

Lemos, Maria Carmen and Joao Lucio Farias de Oliveira (2004), "Can Water Reform Survive Politics? Institutional Change and River Basin Management in Ceara Northeast Brazil," *World Development* Vol. 32 No.12 pp. 2121-2137.

Levinson, Arik, (1997), "A Note on Environmental Federalism: Interpreting some Contradictory Results," *Journal of Environmental Economics and Management* 33, pp.359-366.

List, John and Charles F. Mason (2001), "Optimal Institutional Arrangements for Transboundary Pollutants in a Second-Best World: Evidence from a Differential Game with Symmetric Players," *Journal of Environmental Economics and Management* 42 pp.277-296.

Markusen, James, Edward Morey and Nancy Olewiler, (1995), "Noncooperative equilibria in Regional Environmental Policies when plant Locations are Endogenous," *Journal of Public Economics*, 56, pp.55-77.

McClelland, Nina. *Water Quality Index Application in the Kansas River Basin.* US EPA 907/9-74-001, 1974.

Mobarak, A. Mushfiq, Sunil Rajkumar, and Maureen Cropper (2004). "The Political Economy Of Health Services Provision And Access In Brazil," mimeo, University of Colorado at Boulder.

Noronha, Rudolf de and Elizabeth D. Cardoso, (1996). "Emancipacoes Municipais: Como Ficam os Municipios de Origem?" *Revista de Administracao Municipal, 42 (214)* 67-80.

Oates, W.E., (1972) *Fiscal Federalism*, Harcourt, Brace and Jovanovich, New York, 1972.

________(1981) "On Local Finance and the Tiebout Model" *American Economic Review* Vol.71 No.2, Papers and Proceedings of the Ninety-Third Annual Meeting of the American Economic Association. pp.93-98.

________ (1999) "An Essay on Fiscal Federalism," *Journal of Economic Literature* V.37 pp.1120-1149.

Oates, W.E. and R.M. Schwab. (1988) "Economic Competition among Jurisdictions: Efficiency Enhancing or Distortion Inducing?" *Journal of Public Economics*, 35 333-354.

Revenga, Carmen (2000). "Will there be Enough Water?" in Greg Mock, *Pilot Analysis of Global EcoSystems:Freshwater Systems*, World Resources Institute, Washington, D.C.

Ricardo de Limas Tomio, Fabricio (2002). "The Creation of Municipalities after the 1988 Constitution, " *Revista Brasileira de Ciencias Sociais.* 17: N8 p.61-89.

Sigman, Hilary (2002). "International Spillovers and Water Quality in Rivers: Do Countries Free Ride?" *American Economic Review,* 92: 1152–1159, September.

Sigman, Hilary (2005). "Transboundary Spillovers and Decentralization of Environmental Policies," *Journal of Environmental Economics and Management,* 50: 82-101.

Wolf, Aaron (ed.) (2002). *Conflict Prevention and Resolution in Water Systems*, Edward Elgar, Northampton, MA.

World Bank (2000). *World Development Report 1999/2000*, Washington DC.

World Bank (2003). *World Development Report 2003*, Washington DC.

Figure 1: Quatis and Barra Mansa

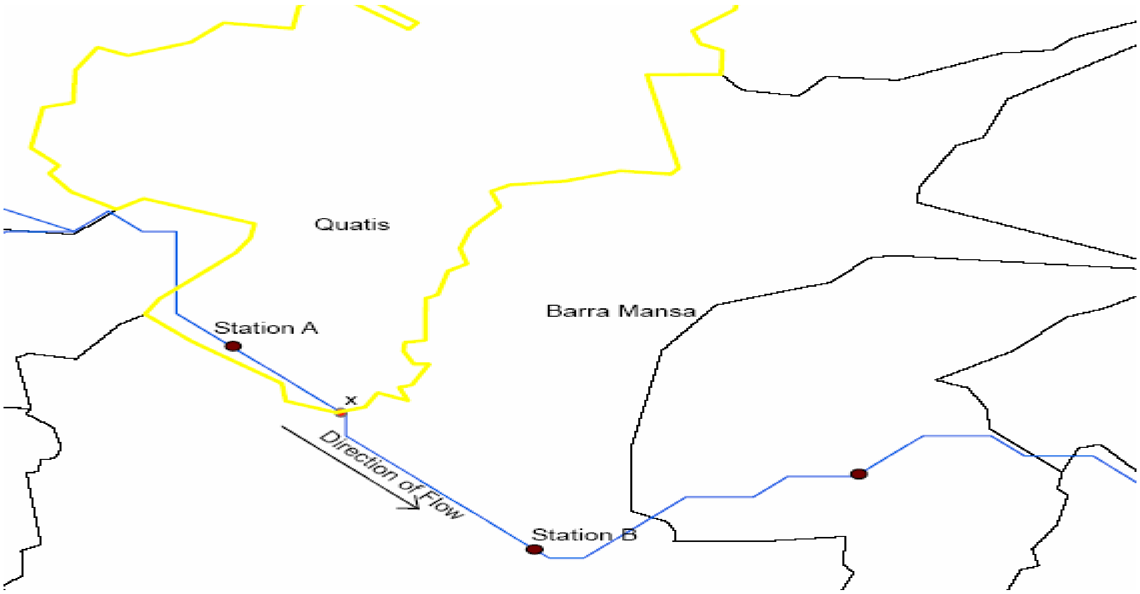

Figure 2: Rivers and Water Quality Monitoring Stations

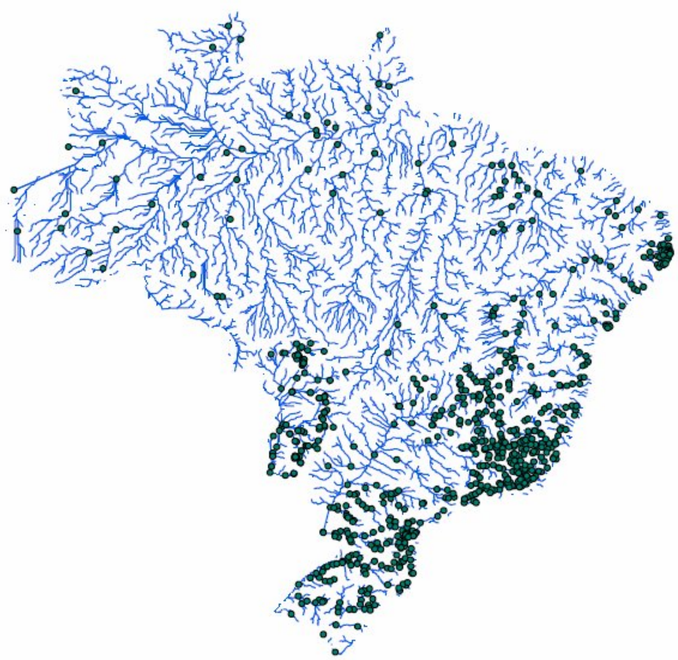

Figure 3: Water Quality Monitoring Stations and County Boundaries

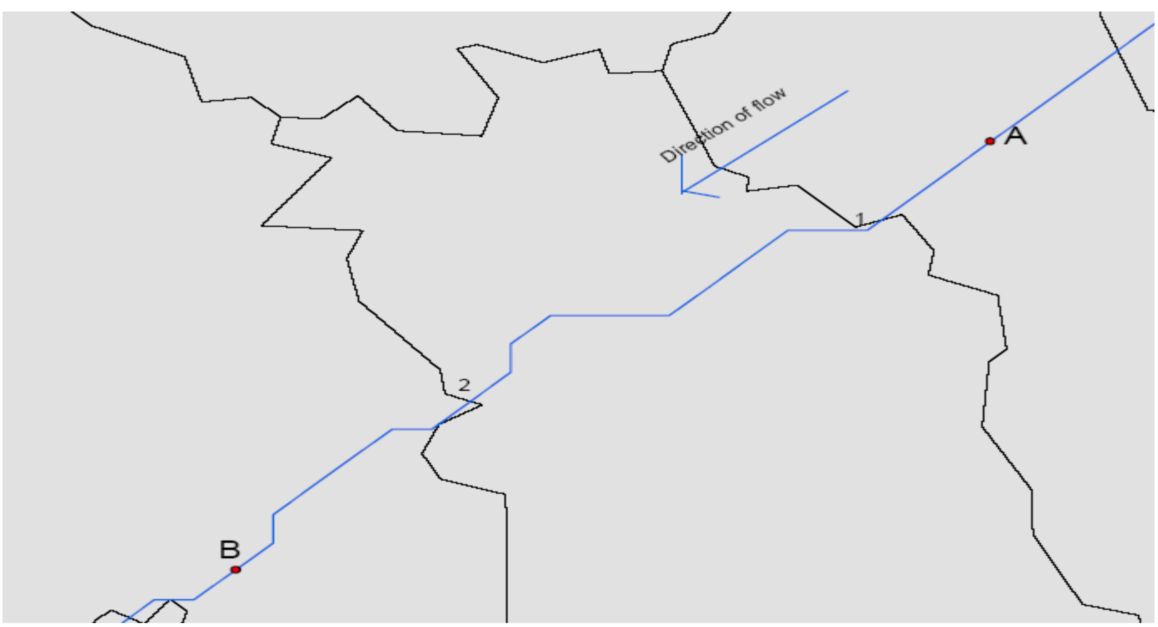

Figure 4: Illustration of Upstream and Downstream Distances

Table 1: Water Quality Summary Statistics

Water Quality Index Summary Statistics

	Observations	Mean	Std. Dev	Min	Max
Downstream WQI	41591	23.6	16.4	0	65
Upstream WQI	40772	39.6	14.5	0	97
Difference in WQI	38935	-16.6	15.6	-93	53

Table 2: River Fixed Effects Regression of Change in Water Quality Index from Upstream to Downstream Station

Dependent Variable: Change in Water Quality Index from an Upstream to a Downstream County
Includes Fixed Effects for Each "River" (Water Body with Contiguous Flow), but not for Station Pairs

Number of County Borders Crossed between Upstream and Downstream WQ monitoring Stations	0.774 (0.134)***	0.568 (0.129)***
Distance Traversed in the Upstream County (in km)		-0.055 (0.017)***
Distance Traversed in the Downstream County (in km)		-0.133 (0.009)***
Distance Traversed in Intermediate Counties (in km)	-0.013 (0.003)***	-0.019 (0.004)***
Distance County Borders Follow the River between Stations (in km)		0.029 (0.008)***
Distance County Border in Downstream County follows river		-0.019 (0.025)
Distance County Border in Upstream County follows river		0.002 (0.021)
GDP in the Upstream County	1.119 (0.476)**	1.345 (0.460)***
GDP in the Downstream County	-0.325 (0.713)	0.115 (0.544)
Population Density in the Downstream County	-8.737 (4.933)*	-5.327 (4.349)
Population Density in the Upstream County	-3.156 (1.895)*	-3.441 (1.857)*
Population Density in Intermediate County	14.896 (7.096)**	6.857 (6.250)
Constant	-94.379 (5.915)***	-118.537 (4.259)***
Observations	21160	21160
Number of Fixed Effects for "rivers" (bodies of contiguous water flow)	255	255
R-squared	0.23	0.25

Robust standard errors in parentheses; * significant at 10%; ** significant at 5%; *** significant at 1%
Regressions control for year, month, and climate region-month fixed effects and for geographical variables affecting inflows into water body measured both at the upstream and downstream stations

Table 3: River Fixed Effects Regression with Controls

Number of Borders Crossed between Stations		0.408 (0.104)**	0.391 (0.104)**
Population Density in Downstream County		-7.858 (2.959)**	-9.096 (3.359)**
Population Density in Upstream County		0.733 (3.249)	-2.077 (2.808)
GDP in Downstream County		1.763 (0.556)**	2.132 (0.764)**
GDP in Upstream County		1.523 (0.747)*	2.336 (0.637)**
Dummy for State Capitals			0.285 (3.667)
Risky housing in Downstream County			-0.404 (0.651)
Agriculture principal Activity in Downstream County			-1.712 (0.866)*
Forestry Principal Activity in Downstream County			4.461 (1.171)**
Fishing Principal Activity in Downstream County			-0.890 (1.473)
Industry Principal Activity in Downstream County			5.827 (1.222)**
Extractive Industry Principal Activity in Downstream County			5.269 (1.139)**
Commerce Principal Activity in Downstream County			2.763 (1.080)*
State capital in Upstream County			3.201 (2.988)
Risky Housing in Upstream County			0.221 (0.630)
Agriculture principal Activity in Upstream County			2.752 (1.252)*
Forestry Principal Activity in Upstream County			2.662 (2.312)
Fishing Principal Activity in Upstream County			-6.127 (1.060)**
Industry Principal Activity in Upstream County			0.059 (1.356)
Extractive Industry Principal Activity in Upstream County			5.056 (1.677)**
Commerce Principal Activity in Upstream County			1.316 (1.104)
State Capital Average in Intermediate Counties			0.002 (0.001)**
Risky Housing Average in Intermediate Counties			-0.000 (0.000)
Agriculture Average in Intermediate Counties			-0.000 (0.000)
Forestry Average in Intermediate Counties			0.000 (0.000)**
Fishing Average in Intermediate Counties			0.000 (0.000)
Industry Average in Intermediate Counties			-0.000 (0.000)*
Extractive Industry Average in Intermediate Counties			0.000 (0.000)
Commerce Average in Intermediate Counties			0.000 (0.000)
Observations		30709	30709
Number of (mean) groupid		294	294
R-squared		0.20	0.26

Table 4: River Fixed Effects Regressions with Additional Control Variables

	Coefficient without controls	Coefficient with Additional Controls	Number of Observations
Gini Coefficient	0.270 (0.093)***	0.206 (0.093)***	30241
Urban Share of Population	0.355 (0.098)***	0.317 (0.098)***	29288
Ethnic Fractionalization	0.270 (0.093)***	0.201 (0.092)***	30241
Primary Economic Activity	0.317 (0.094)***	0.193 (0.098)**	31697
Health Spending Per Capita	0.399 (0.102)***	0.139 (0.106)	27408
Adequate Water Systems	-0.297 (0.137)***	-0.477 (0.140)***	12079

*all of the regressions in Table 4 include control variables for population, GDP, distance to borders, distance between stations, geographic controls, month dummies, year dummies, and climate dummies.

Table 5: Station Pair Fixed Effects Regressions of Change in Water Quality as Water Flows Downstream

Dependent Variable:	Downstream WQ Index-Upstream WQ Index	
Number of Borders Crossed Between Stations	-4.243 (0.471)***	-4.025 (0.517)***
Population Density in Downstream County	-27.525 (3.705)***	-36.649 (5.880)***
Population Density in Upstream County	6.697 (3.586)*	1.294 -2.905
GDP in Downstream County	8.06 (1.015)***	9.134 (1.218)***
GDP in Upstream County	4.852 (1.517)***	6.008 (1.646)***
Distance Traveled by River in Upstream County (1000 km)		-0.126 (0.027)***
Distance Traveled by River in Downstream County (1000 km)		0.018 -0.015
Observations	36231	31697
Number of group(groupid fromst2 tost2)	2220	1818
R-squared	0.2	0.23
Robust standard errors in parentheses * significant at 10%; ** significant at 5%; *** significant at 1%		

Table 6: Station Pair Fixed Effects Regression with Trash Collection

Dependent Variable:	Downstream WQ Index-Upstream WQ Index	
Number of Borders Crossed Between Stations	-4.025 (0.517)***	-4.553 (0.555)***
Population Density in Downstream County	-36.649 (5.880)***	-38.861 (6.286)***
Population Density in Upstream County	1.294 (2.905)	0.834 (2.799)
GDP in Downstream County	9.134 (1.218)***	8.773 (1.203)***
GDP in Upstream County	6.008 (1.646)***	5.329 (1.594)***
Distance Traveled by River in Upstream County (1000 km)	-0.126 (0.027)***	-0.124 (0.030)***
Distance Traveled by River in Downstream County (1000 km)	0.018 (0.015)	-0.003 (0.016)
Trash collection in the Downstream County		0.006 (0.041)
Trash Collection in The Upstream County		-0.204 (0.036)***
Observations	31697	31697
Number of group(groupid fromst2 tost2)	1818	1818
R-squared	0.23	0.23

Robust standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 7: Robustness Checks: Only Stations which began collecting Data before 1989 and 1992

Number of Borders Crossed Between Stations	-4.025 (0.517)***	-4.479 (0.626)***	-4.555 (0.676)***
GDP in Upstream County	6.008 (1.646)***	5.255 (1.595)***	5.360 (1.776)***
GDP in Downstream County	9.134 (1.218)***	8.147 (1.164)***	7.898 (1.343)***
Distance Traveled by River in Upstream County (1000 km)	-0.126 (0.027)***	-0.189 (0.041)***	-0.188 (0.051)***
Distance Traveled by River in Downstream County (1000 km)	0.018 (0.015)	-0.017 (0.015)	-0.018 (0.017)
Population Density in Downstream County	-36.649 (5.880)***	-34.123 (5.797)***	-32.991 (7.802)***
Population Density in Upstream County	1.294 (2.905)	1.777 (2.966)	1.435 (2.993)
Observations	31697	19869	20184
Number of group(groupid fromst2 tost2)	1818	982	998
R-squared	0.23	0.30	0.29

Robust standard errors in parentheses

Table 8: Checking Strategic Placement of Monitoring Stations by Counties

	<1 km to upstream border	<5 km to downstream border	<10 km to downstream border
Number of Borders Crossed Between Stations	0.321 (1.331)	0.753 (1.270)	-2.420 (0.741)***
GDP in Upstream County	33.551 (10.292)***	-0.112 (3.141)	6.514 (1.027)***
GDP in Downstream County	18.402 (8.058)**	7.547 (1.374)***	5.723 (0.842)***
Population Density in Downstream County	-19.975 (17.313)	-1.982 (3.419)	-10.714 (2.391)***
Population Density in Upstream County	-27.457 (11.155)**	-5.321 (5.213)	-1.974 (1.918)
Observations	3041	9292	14908
Number of group(groupid fromst2 tost2)	218	677	1024
R-squared	0.30	0.30	0.26

Robust standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%