# Decentralization and Water Quality:
# Evidence from the Re-drawing of County Boundaries in Brazil

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## Abstract

We examine the effect of political decentralization on pollution spillovers across jurisdictional boundaries. Upstream water use has spillover effects on downstream jurisdictions, and greater decentralization (i.e. 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 the border. We use GIS to combine a panel dataset of over 10,000 water quality measures collected at 372 monitoring stations across Brazil with maps of the evolving boundaries of the 5500 Brazilian counties to study (a) whether water quality degrades across jurisdictional boundaries due to increases in pollution close a river's exit point out of a jurisdiction, and (b) what the net effect of a decentralization initiative on water quality is, once the opposing impacts of inter-jurisdictional pollution spillovers and increased local government budgets for cleaning up the water are taken into account. We take advantage of the fact that Brazil changes county boundaries at every election cycle, so that the same river segment may cross different numbers of counties in different years. We find evidence of strategic enforcement of water pollution regulations; there is a significant increase in pollution close to the river's exit point from the upstream county, and conversely a significant decrease in pollution when the measure is taken farther downstream from the point of entrance. Even in the presence of such negative externalities, the net effect of decentralization on water quality is essentially zero, since some other beneficial by-products of decentralization (in particular, increased local government budgets, and possibly the creation of more homogenous jurisdictions) offsets the negative pollution spillover effects.

## 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 372 monitoring stations located in all eight major river basins across Brazil to examine (a) whether water quality degrades across jurisdictional boundaries due to increases in pollution close a river's exit point out of a jurisdiction, and (b) what the net effect of a decentralization initiative on water quality is, once the opposing impacts of inter-jurisdictional pollution spillovers and increased local government budgets for cleaning up the water are taken into account. We find substantial evidence that Brazilian counties strategically pollute close to the river's downstream exit point out of the county (and conversely, remain clean at upstream locations where the river enters the county), but no evidence that the decentralization initiative causes an overall deterioration in water quality, suggesting the presence of offsetting budgetary effects.

Sigman (2002) uses pollution measures taken at rivers that cross international boundaries to analyze spillovers. We can replicate her approach to 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. Some characteristics correlated with both water quality and county size (which in turn is correlated with distances to jurisdictional borders and boundary crossings) are not observed in the data and therefore remain "omitted," and this can introduce bias in estimated spillover effects.[1]

We then 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 between an upstream and a downstream water quality monitoring station. 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 (or in other words, a fixed effect for each river segment defined by a pair of stations). 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.[2]

Our unit of observation is the station pair, and our dependent variable of interest is the change in *Biochemical Oxygen Demand* (BOD) from the upstream to the

[1] Sigman (2002) notes the need to include monitoring station fixed effects to account for such heterogeneity, but is unable to do so since her border variables of interest do not vary over time.
[2] Sigman (2004) on the other hand uses cross-sectional variation in whether particular U.S. states are authorized to conduct their own enforcement to study the border spillover effects stemming from such authorization.

downstream location: $\Delta BOD = BOD_d - BOD_u$.[3] For the same upstream-downstream station-pair the county re-districting can change the distance the river traverses in the "upstream county" (i.e. where the upstream station is located), the distance traversed in the "downstream county", and the number of county boundary crossings between the pair of stations. We use variation in all three dimensions in order to analyze both strategic pollution spillovers and the net effect on water quality from the decentralization that stems from county splitting. If strategic polluting behavior and inter-jurisdictional spillovers exist, counties would shift polluting activity to near their downstream exit border. Thus pollution level in the upstream county would be greater when measured closer to the exit border, and conversely, pollution level in the downstream county should be lower when measured further away from the upstream entering border. We find strong evidence for both effects, suggesting the presence of spillovers due to such strategic behavior by counties. Further, such strategic pollution shifting also suggests that water quality should fall more dramatically in the upstream county the closer we get to the exiting border, and our regression estimates indicate precisely this type of dynamic for changes in BOD in Brazilian rivers. When we allow for non-linear effects of distance to border, we find that BOD increases by 2.1% for every kilometer closer a river gets to the exiting border, but in the stretch within 5 kilometers of the border this increase jumps to 15% per kilometer.

In spite of such clear evidence on cross-boundary spillovers, we find that the net effect on water quality of having extra boundary crossings induced by county splitting is statistically indistinguishable from zero. When counties split, a larger number of smaller

[3] Sigman (2002) also uses BOD to study pollution in international rivers. BOD is relatively easily measured by standard procedures, helping to ensure data quality. BOD tends to travel farther downstream than some other pollutants, which makes it appropriate for a study on inter-jurisdictional spillovers.

counties start managing the same river segment, which could lead to an adverse effect on water quality due to spillovers, but also a beneficial effect from (a) the increased aggregate public services budgets that accompany decentralization, and (b) the possibly greater homogeneity in population that results. In Brazil county-splitting does lead to an increase in aggregate budgets, since each county receives a fixed (population-based) transfer from upper-level governments called the Municipalities' Participation Fund (FPM) in addition to a portion of the taxes collected in their jurisdiction. Thus when a larger county is split into two smaller counties, the replacement budget for the smaller counties exceeds the original county's budget. Our analysis also offers some direct evidence on budgetary impacts of this form of decentralization that potentially improves water quality. In regressions controlling for county fixed effects, we find that per-capita sanitation spending increases dramatically (just about doubles at the mean) in counties that are split due to the re-drawing of jurisdictional boundaries.

We conduct a number of sensitivity checks to see whether these results are driven by the strategic placement of monitoring stations by the county governments close to their borders, or the selective addition of new stations in areas where the pollution problems are worsening. In addition, we adapt the Altonji, Elder and Taber (2005) estimation methods to assess the potential bias in our estimates from the possibility that counties split for some unobserved reason that is also correlated with a degradation in water quality. If the selection on county splits due to the set of observed explanatory variables (e.g. changes in population density or GDP per capita) is any guide, then the bias stemming from unobservable determinants of county splits is not likely to be very

large, and cannot explain much of the effect of distance to jurisdictional border on levels of BOD.

## 2. The Literature on Decentralization and Water Quality Spillovers

Decentralization has been one of those "buzz-words" promoted by many development scholars and practitioners as a way to improve public service delivery and rural development outcomes. The 2004 World Bank World Development Report on service delivery devotes large sections to the topic. Many multi-lateral development institutions have policies encouraging decentralization. The UNDP's Decentralized Governance Program works with national level 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. However, the relative merits of decentralized versus centralized organization of public services remains a debated topic in the scholarly literature. At issue is balancing the objective of improving accountability and responsiveness of the public sector with the difficulty of providing public goods with benefits or costs that cross jurisdictional boundaries. Identifying conditions under which decentralization improves the efficiency of the public sector remains a key policy challenge.

In its early stages, the contribution of the economics literature to the decentralization debate was primarily theoretical. Oates (1972)'s seminal work on the

topic argues that decentralization improves efficiency if it enables communities to take advantage of heterogeneity in preferences over public goods provision. However, Oates (2001) shows that there are two major sources of inefficiency stemming from decentralization: it allows communities to ignore the externalities that they impose on other regions and it causes duplication in management bureaucracy. List and Mason (2001) show that as long as such spillovers are not too high, decentralization will improve efficiency over a centralized government setting uniform pollution standards, since there may be large variations in the marginal costs of added pollution across localities. Coate and Besley (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 as each community does not pay the full marginal cost of local programs.

Insights from the environmental "race to the bottom" are also relevant for evaluating the merits of decentralization. Cumberland (1981) and others have argued that competition between jurisdictions to attract business investment may lead to a "race to the bottom" in environmental quality. In contrast, Oates (2001) suggests that a "race to the bottom" is unlikely to follow inter-jurisdictional competition, since environmental damage is 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 accurately measuring spillover effects, and in part a result of the impossibility of isolating the effect of decentralization when it is combined with a series of legislative reforms.

Sigman (2002) was the first to examine water pollution spillovers across jurisdictional boundaries. She finds that stations just upstream of international borders have higher levels of BOD than similar stations elsewhere. However, this effect is not robust to the inclusion of country fixed effects, and she herself warns of the dangers of interpreting correlations that may be driven by the cross-country heterogeneity in some other unmeasured characteristic. Sigman (2005) improves this identification strategy in analyzing spillovers across U.S. states following the passage of 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. A key identifying assumption is that authorized states are comparable to other states at the baseline, and the timing and choice of states to authorize is essentially as exogenous event. Her estimation strategy requires identifying the location of monitoring stations relative to borders, and classifying each station as either upstream, downstream, or bordering a state boundary. She uses a fixed 50-mile distance to the border to classify stations into these groups, and finds that a significant number of stations can be categorized in more than one group (i.e. they are both upstream of one boundary and downstream of another). The location of stations relative to state borders lacks any time variation, and empirical identification in the station-fixed-effect regressions comes from time variation in states' authorization status.

In contrast, our approach uses pairs of stations (rather than individual monitoring stations) as the unit of observation to examine changes in water quality from an upstream station to its nearest downstream station. Classification of "upstream' and "downstream" stations GIS river flow vector maps is therefore natural and unambiguous. In addition, since our identification strategy takes advantage of the evolving county boundaries in Brazil over time, we have time variation in each station's distance to the nearest county exiting (i.e. downstream) and county-entering (i.e. upstream) borders. We identify the pollution effect of distance to border solely from *changes in that distance over time for the same monitoring station due to a change in the county boundary*, which reduces concerns about the strategic or non-random placement of monitoring stations relative to county boundaries. Unlike Sigman (2005), this also allows us to identify the effect of being an additional kilometer from the border, and examine non-linear pollution effects by distance to border (i.e. whether pollution increases more dramatically as the river flows downstream very close to the exiting border as opposed to further into the county, away from the border). We can also separately examine pollution attenuation once the river enters the downstream county, since that county has the reverse incentive to be more vigilant in deterring pollution at its own upstream locations close to its entering border. In addition to these distance variables, we also have variation in the number of county boundary crossings for the same river segment over time due to the re-drawing of county boundaries. This variable allows us to examine the *net effect* of the decentralization initiative, accounting for both inter-jurisdictional spillovers and changes in population distribution or increased local government budgets for clean-up that decentralization affords.

Importantly, we examine the impacts of these three variables (distance to exiting border in the upstream county, distance to exiting border in the downstream county, and the number of boundary crossings) while controlling for a full set of station-pair fixed effects, which helps address concerns about omitted variable bias. Station pair fixed effects control for time invariant differences in population heterogeneity, geography, land use, and local economic structure. In addition, we directly control for changes in population density, county size, and GDP over time at all locations between the pair of stations.

## 3. The Setting: Water, County Politics, and County Splitting in Brazil

Brazil's federal political system 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 evaluate the decentralization of water policy in specific regions of Brazil. Brannstrom (2004) reports that decentralization policies encouraging interaction between all levels of government and the communities have been the most successful. 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 focus of and the conclusions the authors draw in these case studies implicitly point to the centrality of

spillovers and the importance of inter-jurisdictional cooperation in managing a shared resource. The case studies take the existence of spillovers as given, and the results indicate that inter-county management groups are 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). Virtually all counties in Brazil had either a ministry responsible for environmental issues or had an environment management council as of 2002, but less than 10% belonged to either an inter-county environmental management association or an inter-county water quality association (IBGE 2003)

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. Industrial dumping is also highlighted as a significant concern in approximately 10 percent of counties.

**Table 1. 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 devolved responsibility for sanitation services to the states in 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 to which areas to extend sanitation services 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. The table below lists the most common forms of county management of pollution.

**Table 2. 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 use of these enforcement mechanisms may not be evenly distributed across any given county: the county administration has an incentive to increase spending on enforcement of pollution restrictions in areas of the county where pollution will be most harmful to community members.

*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 various 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).

The process of creating new counties 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).

Counties receive transfers from both the federal and the state governments, and the 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 (Tomio 2002).

The process of choosing counties to re-district is not random, and not necessarily uncorrelated with variables that affect water quality. For example, if a county is split due to significant ethnic or wealth differences between the separating district and the districts remaining in the county, the two new smaller counties may be more homogenous than the original larger county, which in itself may reallocate resources towards public goods, including pollution abatement (Alesina, Baqir and Easterly, 1999). This is just an example of another mechanism that relates county splitting to water quality changes (along with spillovers and changes in local budgets), and therefore not a concern for the estimation, and may actually help explain the net effect of decentralization on pollution.

An example of a different type of concern would be that counties with strong leadership or community involvement across districts are less likely to have districts separating, so that water quality would in general be lower in split areas. Since our regressions control for a full set of location fixed effects and inference is based only on *changes in water quality over time in the same river segment*, these level differences in water quality are not of concern for bias in the estimates. They may indicate, however, that counties that split are a set of counties with some special characteristic, which limits the applicability of our results to other contexts.

The major concern here is that the non-random process of creating new counties may be endogenous to *changes in* water quality. The most straightforward example is that if districts with large increases in population density are more likely to separate from the county, then changes in boundary crossings would be correlated with changes in water quality for an independent reason (since population density likely contributes to pollution). We address this particular concern by always controlling for population density at all locations between each pair of stations, but the fact remains that there may be other unobserved variables correlated with both county splitting and water quality changes. One solution would be to instrument county splitting, but factors uncorrelated with pollution that affect splits are not easy to identify. We adapt a bias estimation technique developed by Altonji, Elder, and Taber (2005) to estimate the maximum possible bias in our coefficients of interest stemming from unobservable factors affecting county splitting using as a guide the amount of selection in county splits that is due to other regressors that we have data on (such as population density, GDP etc.).[4] We find

[4] Altonji, Elder and Taber (2005) study the effect of catholic school attendance in the presence of selection into catholic schools and the absence of an appropriate instrument for entry into catholic schools. There's

that the estimated bias is quite small, and cannot explain the strong spillover effects we uncover.

## 4. Empirical Analysis

*A. An Example of our Identification Strategy*

Figure 1 plots the counties Quatis and Barra Mansa in the state of Rio de Janero. 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 was entirely within 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 downstream Barra Mansa residents. 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 the border crossing point x, because voters of Quatis were not affected by this pollution. Pollution entering the river at this point flows into Barra Mansa.

Following the spillovers logic, because the distance from station A and its nearest downstream border has decreased, we expect the water quality at station A to be relatively worse (fewer citizens of Quatis will be affected by pollution at station A than would have been affected in the larger combined county, so the administration is likely to reduce local enforcement). In addition, the distance between station B and its nearest

an implicit assumption in this technique that the regressors we have data on are a random subset of all potential regressors correlated with both county splitting and water quality changes. This is quite a reasonable assumption, and in fact, we have data on population density, which is the most likely culprit for creating an endogeneity bias in our estimates.

upstream border has decreased, so we expect water quality at station B to be relatively worse. Since our dependent variables is measured as the change from the upstream measure to the downstream measure ($\Delta BOD = BOD_d - BOD_u$), we expect a positive coefficient on the distance between the upstream station and its nearest border, and a negative coefficient on the distance between a downstream station and its nearest upstream border. We expect this effect of decreased pollution enforcement near downstream borders to be nonlinear: because station A is located relatively far from the new border, the decrease in pollution in the upstream county from being located an additional kilometer farther from the border that we can observe is smaller than it would be had station A been located closer to point x.

*B. Data*

Our unbalanced panel is comprised of water quality measures taken at 795 monitoring stations (which comprise 372 upstream-downstream station pairs) across Brazil in monthly intervals between 1975 and 2004, which results in over 10,000 individual BOD observations.. 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 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.

We chose to use the biochemical oxygen demand measurements of water quality which are commonly collected by the monitoring stations and are used by the EPA and

other water quality experts engaged in managing American lakes and rivers. Biochemical oxygen demand measures the amount of oxygen consumed by microorganisms which feed on organic matter in rivers. Higher BOD is associated with increased bacterial count and organisms in the water, which accumulate wherever there is a high level of pollution from organic matter. It is commonly used to measure pollution from industrial, sewage, and runoff sources, and indicates the general health of the river.

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 BOD measurement from the upstream to the downstream station ($BOD_d$ – $BOD_u$). 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 in the counties where the upstream and downstream monitoring stations are located), year, monthly water basin specific effects, and either station-pair fixed effects in panel data regressions or additional fixed characteristics of the station pair (including flow accumulation, slope of the river bed, depth of the water, distance, and elevation for each station) in pooled quasi-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 in intermediate counties should lead to a decrease in pollution from upstream to downstream ($BOD_d$ – $BOD_u$ decreases), but holding constant downstream sanitation services, an increase in sanitation service provision upstream should decrease $BOD_u$, thereby increasing ($BOD_d$ – $BOD_u$). If pollution spillovers across

jurisdictional boundaries are present, then we expect water quality to deteriorate more (pollution levels to increase by more) if the river segment traverses a larger number of counties (i.e. crosses borders more often). Conversely, if county splitting increases sanitation budgets or makes populations more homogenous, more boundary crossings may be associated with lower pollution.

The coefficient on the distance traversed in the county where the upstream monitoring station is located provides us with a measure of the strategic decision making by local governments on the spatial allocation of pollution abatement or enforcement. Examples of the distance variables we compute are presented in figure 4. Distance traversed in the upstream county is segment A1, between point A where the upstream water quality measures are recorded and point 1 where the river exits that county. The distance traversed in the downstream county where the second monitoring station is located corresponds to segment 2B in figure 4 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, $BOD_u$ should decrease with the distance traversed within the upstream county (which increases $BOD_d - BOD_u$), while $BOD_d$ should decrease with distance traversed within the downstream county (which decreases $BOD_d - BOD_u$). 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. Stations located well within the borders of a county perceive less effects from decentralization, as the county administration has an incentive

to enforce water pollution regulations where many of its own citizens will be affected by introduction of pollutants into the rivers.

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. Because many of the factors which affect the rate of pollution attenuation are geographic and non-time varying, station pair fixed effects controls for these issues. However, the "quasi-cross sectional" river fixed effects regression encompasses much greater expanses of territory with a single fixed effect; we therefore directly control for several of the most important sources of bias from pollution attenuation.

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 basin-month effects, which are separate dummies for each month in each of the eight water basins in Brazil. This is necessary since seasons and other characteristics of rivers vary across regions of Brazil because of its large size. We estimate flow rate, water depth, elevation, and river gradient for each station using GIS modeling and map data provided by the USGS.

We also use panel data for population density, county size, 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 degrades water quality. In addition to controlling for the population density and GDP in the municipalities of the upstream and downstream monitoring stations, we use a distance weighted average of 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. Results**

Our primary estimating equation is the following station-pair (*stp*) fixed effects regression where the unit of observation is (station-pair x month):

$$\Delta BOD_{stp,t} = \alpha_{stp} + \delta_{basin-month} + \gamma_{year} + \beta_1 \cdot \text{Boundary\_Crossings}_{stp,t} + \beta_2 \cdot \text{Distance\_Upstream}_{stp,t} + \beta_3 \text{Distance\_downstream}_{stp,t} + \beta_4 X_{stp,t} + \varepsilon_{stp,t}$$

X is a vector time-varying control variables that have multiple observations for each station pair, including population density, GDP, area size of the county, all measured for both the county where the upstream monitoring station is located, the county where the downstream station is located, and averaged for the other “intermediate” counties that the river segment flows through while getting from the upstream to the downstream station.

The dependent variable is the change in the BOD measure from the upstream to the downstream point. Summary statistics for this variable are provided in table 3. BOD concentrations in Brazilian rivers are relatively high on average. Rivers with BOD greater than 4 mg/l is considered unacceptable for recreational use in the United States, and 40% of observations in our sample fall above this level, with a mean concentration of above 3.5.

If the upstream county strategically pollutes closer to their exiting border due to the spillovers present, we would expect $BOD_u$ to be greater (and therefore $\Delta BOD = BOD_d - BOD_u$ to be lower) at low values for *Distance_upstream*. Hence the coefficient $\beta_2$ is expected to be positive in the presence of spillovers. Conversely, the coefficient $\beta_3$ on distance traveled in the downstream county is expected to be negative. Pollution regulations are more likely to be enforced in the downstream county and there should be some attenuation in the pollution passed on from the upstream county as the river passes farther into the downstream county, all of which decreases $BOD_d$ and therefore $\Delta BOD$. The first model in table 4 therefore provides strong support for spillovers and strategic polluting behavior by counties. The negative coefficient $\beta_3$ implies that the pollution level decreases by 2.5% for every extra kilometer further the river travels before BOD is recorded in the downstream county. Conversely, BOD increases by 1.6% in the upstream county every kilometer closer we get to the exiting border.

If the upstream county is behaving strategically, they would want to dump all the pollution very close to the river's exit point out of the county. In that case, we would expect the pollution effect of distance traversed upstream to be larger when that distance is very small (i.e. when we are close to the border). The other columns in table 4, where

we allow for a non-linear effect of *upstream_distance* show precisely this type of behavior. Within 5 kilometers of the exit border, getting closer to the border increases pollution by 15% every kilometer, whereas outside this range getting closer to the border increases pollution by only 2% per kilometer, and this difference is statistically significant. A similar pattern emerges when we split the effect by a 10-kilometer-of-exit-border cutoff. When we allow for a more continuous non-linearity (with multiple cutoffs and 5km, 10km and 15km from the border), we get a consistent pattern that we illustrate with a heuristic diagram in Figure 5. We find that pollution keeps increasing more and more dramatically the closer we get to the exiting border.

The coefficient on the number of county border crossings is estimated to be very small in all the specifications (about a 1% increase in pollution for every extra border crossed) and is statistically indistinguishable from a zero effect. Taken together with the distance traveled results, this indicates that the de-facto decentralization brought about by county splitting creates some countervailing benefits for water quality that offsets the greater pollution caused by spillovers and counties' strategic behavior.

The specifications in Table 5 uses only stations close to a county border, and these results are supportive of the story of the apparent trade-off between spillovers and offsetting budgetary impacts inherent in the process of decentralization. When we condition on pollution measures taken only at stations close to the border where the spillovers and county strategic behavior is strongest, we find that the net effect of decentralization (i.e. additional boundary crossings) is to increase pollution levels. BOD increases by as much as 21% for every extra county border crossed by the river. This is a

large and quantitatively meaningful impact that takes water in the average river in Brazil from being usable to unusable.

Table 7 presents some ancillary evidence of the budgetary impacts of county splitting. The county fixed effects regression shows that when counties are split, the new smaller counties see the county health and sanitation spending increase by R$13.2 per person over the spending in the larger county that they were a part of in the previous year. For the average county in Brazil, this translates into a 20% increase in expenditures. Thus the story of water quality improving due to increased local government budgets following decentralization, and offsetting the degradation due to greater spillovers appears plausible.

Table 7 tries to address the concern that there is strategic addition of monitoring stations by counties that were concerned about being polluted on by their new neighbors. If new monitoring stations are added in high pollution areas, this could potentially bias the estimation results. Table 7 shows the effect of excluding the pollution measures from new stations created after 1990. This restricts our sample to roughly half of the full sample used in table 4. The estimated coefficients in table 7 are largely similar to those in table 4 when the sample is restricted to stations which have been in existence since 1990. Thus it appears unlikely that strategic or non-random addition of stations biases our estimates.

In table 8 we check whether extreme values of BOD drives the results, but the coefficients of interest appear robust to excluding the extreme 6% (top 3% and bottom 3%) and the extreme 10% of observations.

A further (and possibly the most important) potential source of bias is that some unobservable variable whose is effect is not picked up by the set of station pair fixed effects experience inter-temporal changes that are correlated both with changes in water quality and with the change in the number of border crossings between stations. This could occur if some cause of county splits was also a cause for counties allowing pollution in the water affecting downstream counties. One way to deal with this issue would be to identify an instrumental variable for county border crossings that is uncorrelated with water quality changes, but no plausible instruments for border crossings is available. Therefore, to deal with the issue less directly, we borrow an idea from Altonji, Elder, and Taber (2005) to estimate the potential size of the bias stemming from some such unobservable using the amount of selection from the observed explanatory variables as a guide.

Using the Altonji et al. (2005) estimation strategy for this purpose requires us to make a few key assumptions. First, we assume that the observed variables (such as GDP changes and population density changes) are a random subset of the set of variables that potentially determine county splits (i.e. changes in the number of borders crossed). Second, we assume that there is a large enough set of variables determining border crossings, and that no other unobservable variable completely dominates the determination of border crossings or water quality changes. While these are restrictive assumptions, we do not believe that they are necessarily violated in our dataset: there are many possible reasons that counties may split, and GDP and population density are likely to explain splits at least as well as the other potential causes of county splits.

Following Altonji, Elder and Taber (2005), we estimate the potential bias stemming from unobservables by regressing the potentially endogenous (border crossings) variable on the predicted values of the dependent variable (change in the water quality index) from a regression that excludes the potentially endogenous variable. The resulting coefficient is then weighted by the ratio of the mean squared error from the regression of the dependent variable on the observed independent variables to the variance of the errors from the regression of the potentially endogenous variable on the observed independent variables. Table 10 presents a summary of results. Both variables measuring distance traversed by the river in the upstream county and the downstream county (the two variables that had non-zero statistically significant impacts in our regressions) appear to be slightly biased away from zero, and therefore need to be adjusted. However, the size of the maximum possible bias is small relative to the estimated coefficients. Our estimate of a 1.6% increase in BOD for every kilometer closer we get to the exiting border gets revised to a 1.1% increase in BOD per kilometer. And even after the adjustment on the variable measuring distance traversed in the downstream county, pollution is estimated to decrease by 2.4% for every extra kilometer further the river travels before BOD is recorded in the downstream county. These remain strong and statistically significant impacts.

In table 11, we test our model against a "naïve" "quasi cross-sectional" specification where we do not control for station-pair fixed effects, to assess whether there is any omitted variable bias from the unobserved fixed characteristics of locations. Coefficients on the variables of interest are substantially different in the naïve

specification, indicating a need for caution in testing for spillovers using cross-sectional variation across localities.

## 7. Conclusion

This paper provides evidence of opposing effects on the quality of an important publicly provide good of a particular form of decentralization that results from the re-districting of jurisdictions. The results suggest that decentralization increases the incentives for counties to allow pollution close to borders, but that this effect is wholly offset by some other beneficial side-effects of the process of decentralization, such as increases in local budgets and (possibly) replacing a heterogenous jurisdiction with multiple homogenous communities.

We find evidence of selective enforcement of pollution regulations: water quality is more likely to degrade between two stations if the upstream station is farther from its nearest border, and more likely to improve between two stations if the downstream station is farther from its upstream border. This is consistent with the hypothesis that counties will enforce pollution more in areas where their constituents will be more likely to be harmed from increased levels of pollution. The spillovers and strategic behavior by counties is largest closest to jurisdictional borders, and suggests that policy-makers and institutions such as the United Nations and the World Bank promoting decentralization ought to be more vigilante in assessing the potential spillover costs of decentralization close border areas. Our results also suggest that there could be important gains from 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.

The results described above survive several robustness checks, and appears not to be driven by the strategic placement of monitoring stations by the county governments close to their borders, or the selective addition of new stations in areas where the pollution problems are worsening. There is a remaining possibility that the main source of identification – county border crossings – is driven by unobservables that are correlated with changes in water quality. If the amount of selection on border crossings based on the other observed variables is any guide, then these potential unobservables explain only a small portion of the negative spillover effects of decentralization reported in this paper.

In summary, while there may be many advantages and disadvantages to decentralizing the management of water resources, this paper shows that the inter-jurisdictional spillovers generated from county-level management of water can be very large in magnitude, particularly close to borders. In assessing which is the proper geographic or administrative unit that ought to be in charge of a publicly provided good, the potential cost of such spillovers should be taken into account.

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Figure 1: Example of County Splitting: Quatis and Barra Mansa counties in the State of Rio de Janeiro

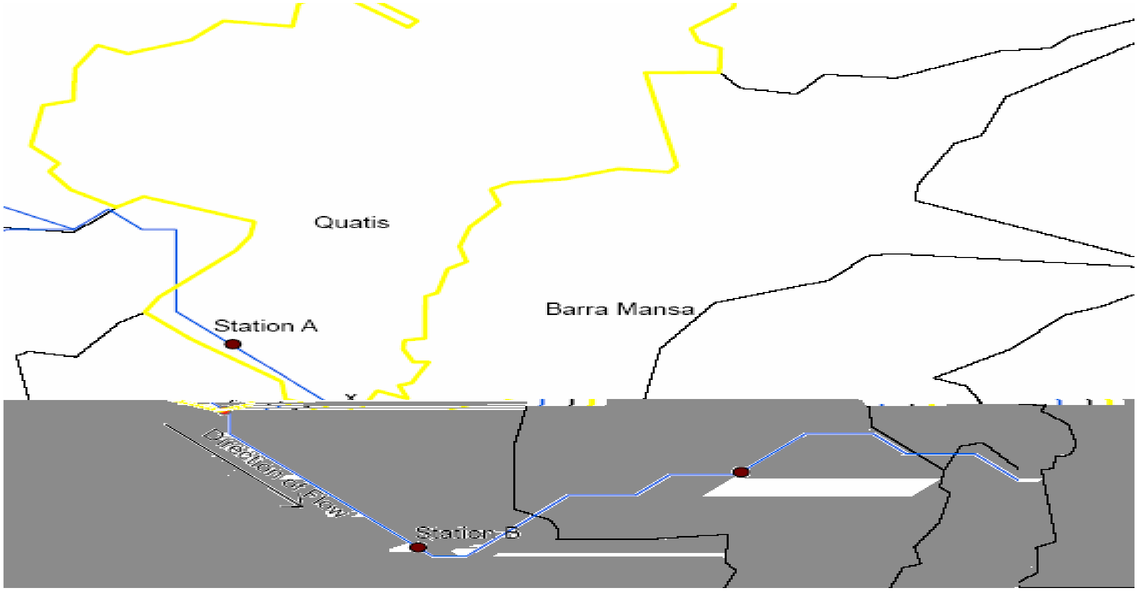


Figure 2: Rivers and Water Quality Monitoring Stations

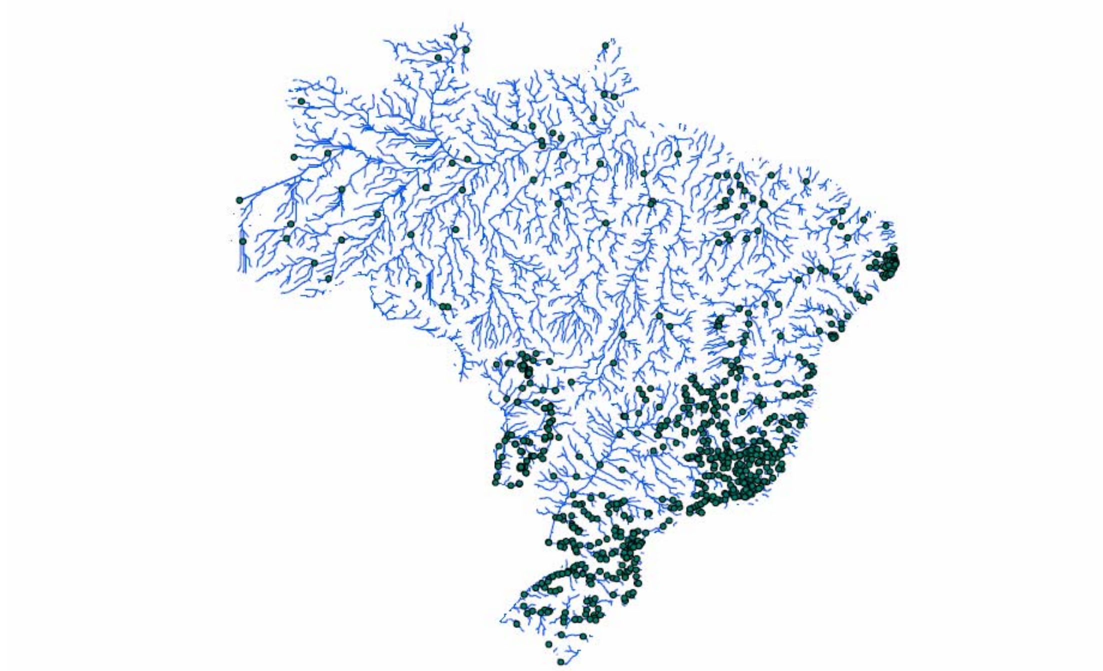

Figure 3: Water Quality Monitoring Stations and County Boundaries

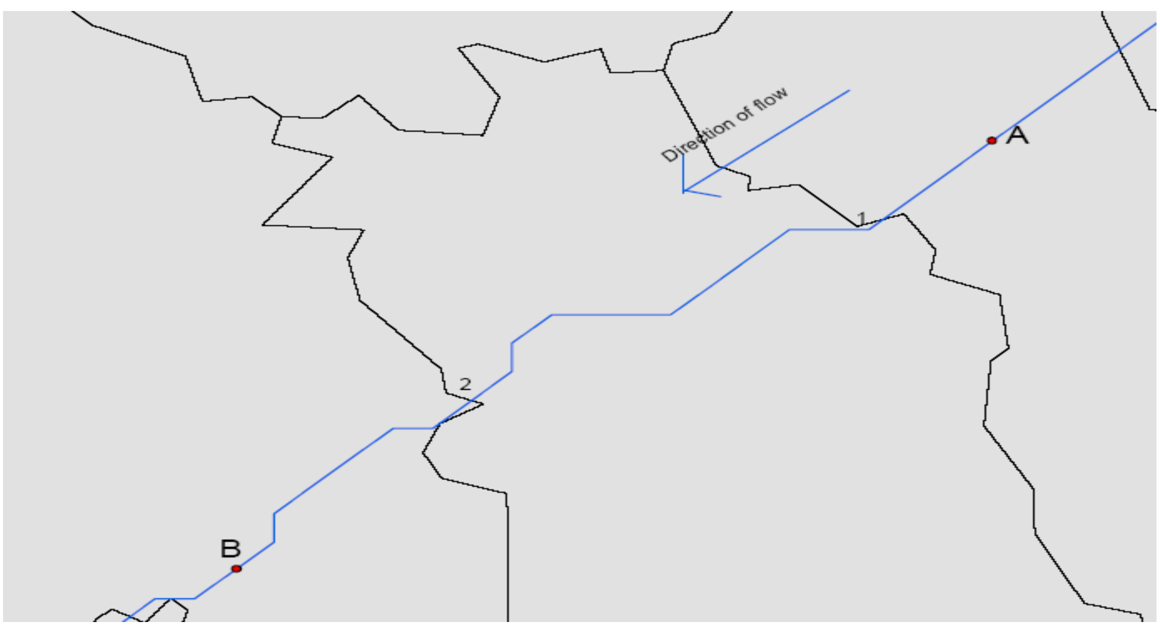


Figure 4: Illustration of Upstream and Downstream Distances

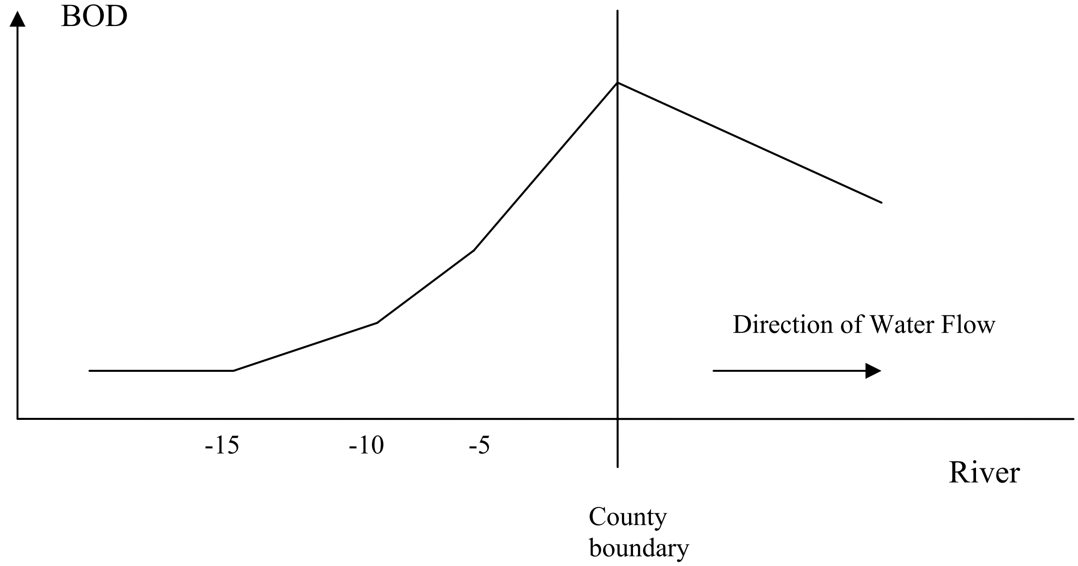


Figure 5: A Heuristic Diagram of the Effects we Estimate

**Table 3. Summary Statistics**

Biochemical Oxygen Demand*

| | Mean | std. dev | Median | Min | Max | Observations |
|---|---|---|---|---|---|---|
| Downstream | 3.42 | 4.11 | 2 | 0.2 | 39 | 13,479 |
| Upstream | 3.7 | 4.44 | 2.1 | 0.2 | 39 | 12,543 |
| Difference | -0.35 | 4.92 | -0.37 | -38 | 37 | 10,282 |

* The top and bottom 1% of observations have been removed from the sample for both the upstream and downstream stations

**Table 4. The Effects of Decentralization on Water Pollution**

| | Biochemical Oxygen Demand | | | |
|---|---|---|---|---|
| Number of County Borders Crossed | 0.0094<br>(0.0289) | 0.0131<br>(0.0292) | 0.0094<br>(0.0288) | 0.0125<br>(0.0290) |
| Distance river passes through downstream county before reaching the monitoring station | -0.0253***<br>(0.0068) | -0.0232**<br>(0.0074) | -0.0267***<br>(0.0063) | -0.0251***<br>(0.0068) |
| Distance river passes through upstream county | 0.0155***<br>(0.0031) | | | |
| Distance river passes through upstream county if the station is w/in 5km of the border | | 0.1544***<br>(0.0248) | | |
| Distance river passes through upstream county if the station is beyond 5km of the border | | 0.0213***<br>(0.0031) | | |
| Distance river passes through upstream county if the station is w/in 10km of the border | | | 0.0868***<br>(0.0220) | |
| Distance river passes through upstream county if the station is beyond 10km of the border | | | 0.0303***<br>(0.0053) | |
| Distance river passes through upstream county if the station is w/in 15km of the border | | | | 0.0022<br>(0.0040) |
| Distance river passes through upstream county if the station is beyond 15km of the border | | | | 0.0150***<br>(0.0027) |
| R-squared | 0.059 | 0.060 | 0.060 | 0.059 |
| N | 10227 | 10227 | 10227 | 10227 |

Other regressors included whose coefficients are not reported: Station pair fixed effects, year dummies, basin-month dummies, and population density, GDP and county size controls in upstream, downstream, and intermediate counties

**Table 5. Conditioning on Stations close to County Borders**

| | Upstream station | | Downstream Station |
|---|---|---|---|
| | Less than 5k from border | Less than 10km from border | Less than 5k from border |
| Number of Borders Crossed | 0.2127* | 0.2089** | 0.1219 |
| | (0.0837) | (0.0722) | (0.0718) |
| Distance river passes through downstream county before reaching the monitoring station | 0.0043 | -0.0151* | 0.0361 |
| | (0.0160) | (0.0072) | (0.1493) |
| Distance river passes through upstream county | 0.2136*** | 0.2516*** | 0.1683*** |
| | (0.0308) | (0.0273) | (0.0254) |
| R-squared | 0.067 | 0.069 | 0.067 |
| N | 3110 | 4919 | 3623 |

Included but not reported: station pair fixed effects, year dummies, basin month dummies, area controls in upstream, downstream, and intermediate counties

**Table 6. Effects of County Splitting on County Budgets/Expenditures**

| | Health and Sanitation Spending (R$) | Capital Spending | Investment | Assessed Municipal Share |
|---|---|---|---|---|
| | 13.2073*** | 28.6702*** | 29.0604*** | 65.6582*** |
| County split | (0.7384) | (0.9567) | (0.9218) | (1.5592) |
| R-squared | 0.517 | 0.223 | 0.181 | 0.631 |
| N | 59712 | 61449 | 61449 | 52391 |

* County fixed effects and year dummies are included in all specifications.

**Table 7. Conditioning on Stations that Existed Prior to 1990**

| | Biochemical Oxygen Demand | | |
|---|---|---|---|
| Number of Borders Crossed | 0.0062<br>(0.0281) | 0.0068<br>(0.0280) | 0.0080<br>(0.0281) |
| Distance river passes through downstream county before reaching the monitoring station | -0.0260***<br>(0.0071) | -0.0270***<br>(0.0067) | -0.0255***<br>(0.0071) |
| Distance river passes through upstream county | 0.0251*<br>(0.0121) | | |
| Distance river passes through upstream county if the station is w/in 10km of the border | | 0.0893*<br>(0.0396) | |
| Distance river passes through upstream county if the station is beyond 10km of the border | | 0.0422**<br>(0.0148) | |
| Distance river passes through upstream county if the station is w/in 15km of the border | | | 0.0117<br>(0.0143) |
| Distance river passes through upstream county if the station is beyond 15km of the border | | | 0.0208<br>(0.0107) |
| R-squared | 0.077 | 0.078 | 0.077 |
| Number of Observations | 4298 | 4298 | 4298 |

*Included but not reported: Station pair fixed effects, year dummies, basin-month dummies, and population density, GDP, and county size controls in the upstream, downstream, and intermediate counties

**Table 8. Sensitivity Test: Excluding Extreme BOD Observations**

| | Excluding the following x% of top and bottom BOD observations: | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 3 % | 5% | 3% | 5% | 3% | 5% | 3% | 5% |
| Number of Borders Crossed | -0.0469<br>(0.0302) | -0.0297<br>(0.0300) | -0.0449<br>(0.0304) | -0.0280<br>(0.0302) | -0.0457<br>(0.0301) | -0.0285<br>(0.0299) | -0.0431<br>(0.0303) | -0.0267<br>(0.0301) |
| Distance river passes through upstream county | 0.0118***<br>(0.0031) | 0.0207***<br>(0.0027) | | | | | | |
| Distance river passes through upstream county if the station is w/in 5km of the border | | | 0.1302***<br>(0.0168) | 0.1071***<br>(0.0168) | | | | |
| Distance river passes through upstream county if the station is beyond 5km of the border | | | 0.0166***<br>(0.0027) | 0.0244***<br>(0.0026) | | | | |
| Distance river passes through upstream county if the station is w/in 10km of the border | | | | | 0.0508**<br>(0.0176) | 0.0576***<br>(0.0166) | | |
| Distance river passes through upstream county if the station is beyond 10km of the border | | | | | 0.0199***<br>(0.0044) | 0.0283***<br>(0.0040) | | |
| Distance river passes through upstream county if the station is w/in 15km of the border | | | | | | | -0.0038<br>(0.0039) | 0.0090*<br>(0.0044) |
| Distance river passes through upstream county if the station is beyond 15km of the border | | | | | | | 0.0112***<br>(0.0026) | 0.0204***<br>(0.0024) |
| R-squared | 0.055 | 0.062 | 0.056 | 0.062 | 0.055 | 0.062 | 0.055 | 0.062 |
| N | 9211 | 8494 | 9211 | 8494 | 9211 | 8494 | 9211 | 8494 |

Included but not reported: Station pair fixed effects, year dummies, basin-month dummies, and population density, GDP, and county size controls in upstream, downstream, and intermediate counties

**Table 9. Altonji, Elder and Taber (2005) Estimate of bias**

Maximum bias if observed regressors are a random subset of all possible regressors
Station Pair regressions

| | Bias | Standard Error ( | Bias max |
|---|---|---|---|
| Municount | -0.001991 | 0.0116284 | -0.024783 |
| Upstream Routelength | 0.0002508 | 0.002069 | -0.004306 |
| Downstream Routelength | -0.0000371 | 0.0003089 | -0.000643 |

**Table 10. Bias in "Quasi Cross-sectional" River Fixed Effects Regressions**

| | Biochemical Oxygen Demand | |
|---|---|---|
| | 0.0173 | 0.0094 |
| Number of Borders Crossed | (0.0106) | (0.0289) |
| | -0.0029* | 0.0155*** |
| Distance river passes through upstream county | (0.0014) | (0.0031) |
| Distance river passes through downstream county | -0.0031 | -0.0253*** |
| before reaching the monitoring station | (0.0025) | (0.0068) |
| | 0.0000 | -0.0001 |
| Population density in the Downstream Counties | (0.0002) | (0.0005) |
| | -0.0001 | -0.0003 |
| Population density in the Upstream counties | (0.0001) | (0.0004) |
| Average population Density in the Intermediate | -0.0001 | 0.0014* |
| Counties | (0.0003) | (0.0007) |
| Average GDP in Intermediate Counties in millions of | -0.0260 | 0.0610 |
| R$ | (0.1041) | (0.0730) |
| | 0.0926 | -0.0432 |
| GDP in the Upstream County in millions of R$ | (0.0786) | (0.0321) |
| | -0.0100 | -0.0514* |
| GDP in the Downstream Counties in millions of R$ | (0.0278) | (0.0251) |
| River fixed effects? | Y | N |
| Station pair fixed effects? | N | Y |
| R-squared | 0.075 | 0.059 |
| N | 10227 | 10227 |