

Damming the Commons

An Empirical Analysis of International Cooperation and Conflict in Dam Location

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Abstract

This paper examines whether countries consider the welfare of other nations when they make water development decisions. The paper estimates econometric models of the location of major dams around the world as a function of the degree of international sharing of rivers. The

analysis finds that dams are more prevalent in areas of river basins upstream of foreign countries, supporting the view that countries free ride in exploiting water resources. There is weak evidence that international water management institutions reduce the extent of such free-riding.

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Large water development projects are a hallmark of modern and industrializing economies. Nearly one-half of the world's rivers have at least one large dam (World Commission on Dams 2000) and dam construction proceeds at a rapid rate.² Large dams have complex welfare implications. Dams provide valuable services to their beneficiaries, including hydropower, irrigation, urban water supply, navigation, flood control. However, for at least 50 years, economists have worried that the benefit-cost analysis methods employed to assess the welfare impacts of dams have overstated benefits and understated costs (Eckstein 1965).³ This concern has grown with rising attention to (and willingness to pay for) the environmental amenities of free-flowing rivers in industrialized countries, and the social disruption that follows forced resettlement of populations in a new dam's catchment area in developing countries. Previous research has emphasized the limited systematic empirical evidence for the effects of large

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² A "large dam" is one that is 15 or more meters tall, or between 5 and 15 meters with a water storage capacity of at least 3 million m³ (Scudder 2006). The United States has more than 6,000 large dams, many of the largest (Hoover, Grand Coulee, Glen Canyon) constructed between 1935 and 1965 (Collier et al. 2000). Before 1949, China had fewer than 100 large dams; in 2006, it had 22,000, about one-half of the world's total (Scudder 2006). In the Amazon Basin alone, 140 dams are in the planning stages in Brazil, Bolivia, Colombia, Ecuador and Peru (International Rivers 2010).

³ For example, an analysis of the Central Arizona Project, which was completed in 1987 and provides water to the City of Phoenix, suggests that the project was built 86 years too early, with a deadweight loss of more than \$2.6 billion, and that exploiting groundwater sources to delay its construction would have been more efficient (Holland and Moore 2003).

dams on social welfare within a country and has started to fill this gap (Duflo and Pande 2007; Holland and Moore 2003; Strzepek et al. 2008; Strobl and Strobl 2011).

As the main mechanism for diverting water from rivers, dams also pose an important common property problem that has not been addressed in the literature. Even if countries make efficient decisions about dam construction on domestic rivers, countries sharing a river may over-develop the river if they are able to pass some of the costs imposed by dams to other countries. The resulting spillovers (or “spill-unders” if the problem is excessive water diversion) may create the potential for conflict across borders of countries sharing a river.

Sharing of water resources is common: the watersheds of the world’s 276 international rivers cover more than 45 percent of the Earth’s surface (Wolf et al. 1999, TFDD 2014). Current high-profile conflicts regarding dams in international river basins include a dispute between Ethiopia and Egypt over an Ethiopian dam that will reduce the flow of the Nile River as it flows downstream into Egypt, and one between China, Myanmar and Thailand over China’s plans to dam the upstream reaches of the Nu River.⁴ Disputes over allocation of shared rivers may escalate with population growth and the impacts of climate change, which may include increasing aridity in some regions and increasing variability of renewable water supply in many others (Postel and Wolf 2001).

This paper examines whether countries consider the welfare of other nations that share water resources when they make water development decisions. We estimate econometric models that allow the number of major dams in drainage basins around the world to be a function of the degree of international sharing of rivers, controlling for other factors. Our basic model tests the hypothesis that

⁴ On the Ethiopia/Egypt conflict over the Nile, see: Witte, Griff. 2013. Egypt frets, fumes over Ethiopia’s Nile plan. *Washington Post*, 12 June. On China’s plans for Nu River dams, see: Jacobs, Andrew. 2013. Plans to harness Chinese river’s power threaten a region. *New York Times*, 4 May.

countries are more likely to build dams, especially those with downstream costs, when downstream countries bear some of the costs. We also investigate the role of international watershed management institutions in mitigating this effect.

We find evidence that dams are more prevalent in areas of river basins upstream of foreign countries, supporting the view that countries put lower weight on downstream countries' costs than their own costs in deciding whether to build dams. We find suggestive, but very weak, evidence that international water management institutions reduce the extent of such free-riding.

The structure of the paper is as follows. The paper begins with a brief review of previous literature that considers dam placement and transboundary spillovers in rivers, as well as the potential mitigating impacts of international agreements. Section 2 describes the sources of our data and the GIS analysis conducted to generate our variables of interest. Section 3 presents the results of our main equations. Section 4 considers several extensions, including analyses that break down results by type of dam and consider the role of international water management institutions. Section 5 briefly concludes.

1. Previous Literature

Substantial anecdotal evidence suggests that political jurisdictions free-ride in the allocation of shared water resources (Gleick 1993). Much of the economic literature on this topic develops the theory of common pool resources, using game theory and drawing upon specific case studies of shared rivers (Rogers 1969, Frisvold and Caswell 2000). Prior studies suggest that the incentive to free-ride in international surface water allocation can sometimes be overcome. Becker and Easter (1999) consider the U.S. states and Canadian provinces sharing the Great Lakes and show that a relatively small coalition

can provide a stable cooperative outcome, given the distribution of gains and losses in the region from cooperating over water diversions.⁵

Studies that examine shared rivers empirically have mostly focused on water pollution. Empirical analyses of water pollution spillovers in transboundary settings have found that countries, and even states and counties, free-ride in water quality. Water pollution levels are higher near international borders (Sigman 2002, Bernauer and Kuhn 2010) as well as near subnational borders within countries (Sigman 2005, Lipscomb and Mobarak 2013, Cai *et al.* 2013, Kahn *et al.* 2013). Water pollution emissions by U.S. pulp and paper plants appear to be higher when out-of-state residents receive a greater share of pollution control benefits (Gray and Shadbegian 2004).

Our analysis in this paper extends this empirical approach to water impoundment and withdrawal.⁶ Many types of dams impose significant downstream costs. Dams that impound water for consumptive urban water supply reduce the quantity of water available downstream. Irrigation dams increase water diversion for agriculture, which consumes some water, and the quality of irrigation return flows is often degraded; thus, they also impose costs downstream. Hydroelectric dams are only minimally consumptive but impose significant downstream costs by altering a river's hydrological cycle: they change the magnitude and timing of seasonal flows, alter water temperature, block the movement of fish and other species, and modify the rate and quality of sediment deposition (Richter et al. 2010, Harpman 1999). Thus, when countries consider the perceived benefits and costs of constructing a dam

⁵ There is also a significant literature on the common-pool problem of groundwater management, focusing on spatial well interference and intertemporal pumping externalities due to the slow (or zero) rate of recharge (for example, Gisser and Sanchez 1980).

⁶ One advantage of our method over the empirical approaches used to study water resources is our ability to include all locations in major watersheds: research on in-stream water quality must consider the locations where countries choose to locate pollution monitors. This design raises the possibility of strategic or at least unrepresentative positioning of monitors, whereas we are able to work with a universe of locations.

in a given location, they are more likely to find the project desirable when an international border makes some of these downstream costs less salient.⁷

Although the economics literature contains no empirical research on free riding in water withdrawal, water quantity has been a much greater source for international conflict than water quality. Water availability is a central concern at all levels of development, and once water is diverted for consumptive use, it is no longer available for downstream countries. In contrast, water pollution tends to receive greater attention in higher income countries, and water can be treated by downstream countries if quality is impaired. Therefore, the common property problem may be more severe for water quantity than water quality, but it may also receive more attention and thus be better controlled by institutions.

Our analysis also considers whether free-riding in international water allocation is mitigated by treaties. Given frequent disputes over shared rivers, the degree of cooperation facilitated by global water treaties may be very high (Wolf 1998). On the other hand, previous research on air pollution provides reason for skepticism about the extent to which international environmental treaties constrain behavior (Murdoch *et al.* 1997, Beron *et al.* 2003). A growing body of research examines conditions for adoption of international water management institutions (Espey and Towfique 2004, Song and Whittington 2004, Dinar 2008, Dinar *et al.* 2010). Since treaties may be endogenous, we will draw upon this literature in modeling the impact of treaties on dam construction.

2. Data

⁷ Thus, we do not argue that countries seek locations that export costs, but rather that they are more likely to go ahead with feasible projects where costs are “discounted” by being partially exported.

In our econometric analysis, we examine the frequency of dams in an area as a function of the sharing of the water resource and other characteristics that may affect the benefits and costs of dams in a location. We use Geographic Information System (GIS) software to create dependent variables, measures of resource sharing, and other explanatory variables. We define observations at the level of a geographic subbasin-country area: the intersection between a “subbasin” of a major river system and a country. Using the subbasin to define the unit of observation for dam counts is necessary because dam demand and supply characteristics (e.g., population and hydrological suitability for dam construction) vary by subbasin. Intersecting these units with country borders allows us to model countries’ decision making about dam placement.

Subbasins are defined by the HYDRO1k dataset from the US Geologic Survey (USGS), which uses global elevation data to divide land area into river basins and subbasins (USGS 2012). The subbasins are coded using the Pfafstetter system (Verdin and Verdin 1999), which provides a hierarchical coding of river basins and their subdivisions into several possible levels of subbasins. The finest subbasin classification has 6 digits. We rely on the 3-digit subbasin level as our basic unit of observation for tractability.⁸ The Pfafstetter system codes basins in a way that makes it possible to identify whether each subbasin lies upstream of the others and thus is the basis of our count of downstream countries. An additional restriction was necessary because not all the areas coded with the same first digit by the Pfafstetter identifier share a river mouth.⁹ To fix this problem, we used additional river basin data from

⁸ This choice facilitates the analysis but does mean that our coding misses upstream-downstream relationships in about 60 small coastal basins where the entire major river basin is only one 3-digit subbasin in HYDRO1K.

⁹ Given the system’s need to identify only 10 first-digit basins within a continent, a coastal area with many smaller rivers all draining to the sea can have many subbasins with the same first digit. In our analysis, the shared first digit initially gave a false impression of upstream-downstream relationships between some subbasins that are actually in different river basins.

the Global Runoff Data Centre (GRDC 2007). The GRDC defines 405 major world river basins (also based on the HYDRO1k analyses) and we restrict our analysis to areas within these major basins.¹⁰

Our main unit of observation intersects the river subbasins defined by HYDRO1k with international borders. Most subbasins are within a single country. A number of subbasins, however, are split by country borders; these subbasin-country areas are treated in the database as two or more separate observations. Table 1 describes the distribution of subbasin-country areas, subbasins, and major river basins across continents in 2005.¹¹

To construct the dependent variables, we placed dams in subbasin-country areas using the Global Reservoir and Dams (GRanD) dataset, a newly-available data set that provides geocoding for 6,862 of the world's largest dams and reservoirs (Lehner *et al.* 2011). GRanD includes all dams with reservoirs that have storage capacity greater than .1 km³ and a number of dams with smaller reservoirs. We use a total of 4,696 (just over two-thirds) of the dams described in the GRanD data because we must restrict our analysis to dams in major river basins. GRanD provides some information on the characteristics of the dams that we can take into account in our analysis. For example, GRanD classifies dams by use and reports total reservoir capacity and dam height. Table 2 reports the main use category for all the dams in GRanD. The most frequent use is irrigation, followed by hydroelectricity;

¹⁰ We can only use 383 of the 405 GRDC basins because HYDRO1k data are not available for the 22 basins on the Australian mainland (although one GRDC basin in Tasmania has HYDRO1k data and is included). In addition, we drop the subbasin-country areas in the Lake Chad basin because this basin has multiple inland mouths, making the Pfafstetter system inadequate to the task of defining upstream-downstream relationships.

¹¹ The country borders are those in effect in 2005 according to CShapes (Weidmann *et al.* 2010), which reports country borders over time. We used CShapes because we aspired to use fixed effects equations that identified the effects of free-riding in dam placement through changes in country borders. However, analysis of the data found only 2 sets of border changes that could be used for this purpose: the breakup of the Soviet Union and the separation of Namibia from South Africa. In our data, no dams were built in any of the areas that experienced a change in status, so the panel data analysis is not reported.

unfortunately, the data lack information on use for 23 percent of dams. The second panel of columns in Table 2 describes the distribution of dam types, considering only the dams in GRDC basins – our sample. The fraction of missing values is smaller, though overall the distribution of types is similar to that among all dams, with slightly more irrigation dams, and even smaller differences in the fraction of dams used mainly for water supply, flood control, and recreation.

The lower panel of Table 1 reports some additional information on the dams used our analysis. First, it reports the counts of by dams by continent, showing that North America has the highest number. Because GRanD provides the universe only of dams with reservoirs greater than $.1\text{km}^3$, we also report some analyses that exclude dams with smaller reservoirs. 2071 dams (44% of the 4696 used the analysis) have these large reservoirs. To focus on dams with the most significant downstream costs, some of our analysis is also restricted to dams that list water supply, irrigation, or hydroelectric power generation as the main or a major use. As Table 1 reports, this subset includes 2965 dams (or 63% of the total). One extension considers funding by the World Bank; Table 1 shows that a small number of the dams across all continents (except in Australia and the South Pacific) received this funding.

Our key explanatory variables are the presence and number of countries downstream of each subbasin-country area. We use the upstream-downstream relationships embedded in the Pfafstetter coding to identify the subbasins from each subbasin-country area and whether they are in the same country.¹²

¹² We are grateful to Georgia Bush for writing a program in R that does this calculation. For each subbasin-country area, the program iterates through all of the other subbasin-country areas in each GRDC river basin and determines whether any of the subbasins that the Pfafstetter coding indicates are downstream of this country are in different countries than the current observation.

Several additional covariates were also included to control for other sources of variation in dam counts. Table 3 reports summary statistics for the variables over the observations we are able to include in our analysis. It also divides observations by our principal explanatory variable, the presence of at least one foreign country downstream of the subbasin. The size of each subbasin-country area (in km²) addresses the likelihood that larger areas will contain more dams. As Table 3 reports, areas upstream of an international border have more dams, and more dams of all the subtypes, than other areas. We also include the number of downstream subbasins, regardless of whether they are in the same country or a different one. The likelihood of finding a different downstream country is higher for areas that are further upstream. If dams are simply more likely to be located either upstream or downstream in a basin, such a tendency might otherwise confound the indicator we use for shared resources. As Table 3 reports, areas with a downstream country have on average twice as many downstream subbasins as other areas, but the two groups of observations do overlap substantially in this variable.

We also include several measures of the physical suitability and need for dams in the subbasin-country area. We control for slope, since areas with higher slope present better opportunities for dam construction. The Compound Topographic Index (CTI), a function of the slope and the upstream area contributing to flow, is a time-invariant wetness index that is highly correlated with soil moisture and might measure demand for irrigation water.¹³ Both slope and the wetness index are available from HYDRO1K; the variables used in the analysis are the averages over the 6-digit subbasins in each of the 3-digit Pfafstetter subbasins.¹⁴ As another measure of demand for dam services, we calculated

¹³ Specifically, $CTI = \ln(\text{flow accumulation} / \tan(\text{slope}))$. If the slope is equal to zero, the formula uses $\text{slope} = .001$. In our data, the index ranges from a minimum of about 3, to a maximum of about 11.

¹⁴ In previous versions of the equations, we also included local historical precipitation, calculated using gridded data on precipitation from 1950 through 2000 (Fekete *et al.* 2002). The estimated coefficients on local historical

population within each subbasin-country area, using the spatial data from the Gridded Population of the World version 3 (GPWv3), which provides estimates of population density in 2000 (CIESIN 2005).¹⁵

3. Data Analysis and Results

Our basic econometric model estimates the determinants of the number of dams in an area:

$$\log(Dams_{ij}) = \beta C_{ij} + \gamma \log X_{ij} + \alpha_i + u_k + \epsilon_{ij} \quad (1)$$

in which $Dams_{ij}$ is the count of dams in the portion of country i that lies within river subbasin j , C_{ij} is either an indicator for any downstream foreign countries or the count of these countries, X_{ij} is a vector of other characteristics of a country-subbasin, α_i is a country fixed effect, u_k is a river basin fixed effect, and ϵ_{ij} is the standard econometric error term. A log-log relationship was chosen for the relationship to allow proportionality between the number of dams and the major variables, especially area.¹⁶

3.1 Main results

Table 4 reports estimates of the coefficients for equation (1). All of the estimated equations include dummies for the country and the major river basin, although these coefficients are not reported.

Standard errors are clustered at the river basin level to address concerns about spatial heterogeneity.

precipitation were small and statistically insignificant in all equations and are not currently shown in the tables. Dams do not appear to be either a substitute or complement for rainfall, once we control for basin and country effects and other covariates.

¹⁵ We use the GPWv3 grid that adjusts local population estimates to make them consistent with UN population estimates. We use the population grid for 2000, the most recent one available based on observed data. GPWv3 shows density in 2.5 arc-minute grid cells, which are about 5 km wide at the equator. Superimposing our subbasin-country areas on this grid allows us to calculate population density for each observation.

¹⁶ To allow areas with no dams to remain in the analysis, .1 was added to all dam counts before taking logs. In Column 5 of Table 4, the conditional-on-positive estimates, the values revert to the true value of the dam counts in logs. The statements in the text about statistical significance of the downstream-country variables largely remain true if the functional form is linear and the dam count variable is an average geographic density of dams.

By allowing correlation within basins, this clustering makes the equations robust to the possibility that the density of dams upstream in a watershed may affect dam density downstream.

Column 1 of Table 4 contains the most basic equation. The coefficient on the presence of a different country downstream is positive and statistically significant. The point estimate of this coefficient, .263, suggests 30 percent more dams in subbasins where water is shared with another country than in those where it is not. Column 2 considers only dams with reservoir capacity greater than .1 km³. The GRanD project sought to geocode all dams with reservoirs of this size and provides information on some dams with smaller reservoirs, when information was available. Column 2 excludes these smaller dams from the analysis to address potential concern about non-random selection of these dams. The coefficient on the presence of a downstream country falls somewhat when only large-reservoir dams are considered and is only statistically significant at 10%. The reduction in the point estimate between Columns 1 and 2 may result from a non-random selection of smaller dams that is somehow correlated with our main variable. However, it might also occur because the location of very large dams is more constrained by physical geography and thus less sensitive to the common pool problems on which we focus.

In Column 3 of Table 4, the measure of resource sharing is broadened: in addition to the presence of a downstream country, the equation in column 3 includes the log of the number of downstream countries. Coasean bargaining between upstream and downstream countries may resolve the spillover more readily when a smaller number of countries bear the downstream costs. The coefficient on the presence of a downstream country remains statistically significant and positive, but the downstream country count has a small, negative, statistically insignificant coefficient. This pattern is consistent with a lack of successful bargaining over the spillover: all that matters is the downstream shifting of costs.

Columns 4 and 5 of Table 4 consider alternative functional forms for the relationship. Column 4 contains a probit for the presence of at least one dam in the subbasin-country area, whereas Column 5 reports an OLS model that is conditional on the presence of at least one dam. The coefficient on the presence of a foreign country downstream is positive in both these equations, statistically significant at 1% in the conditional-on-positive equation in Column 5, and weakly significant in the probit. The point estimates suggest that the intensity of dams conditional on the presence of dams may be more sensitive to resource sharing than the unconditional value (.407 versus .263). One interpretation of this pattern is that the benefits of the first dam in a region are greater than the benefits of subsequent dams. The apparent cost reduction from exporting some downstream costs may be thus more likely to tip the balance for additional dams than for the first dam.

In addition to the coefficients of the variables reflecting resource sharing, several other variables enter the equations with statistically significant coefficients. Not surprisingly, the extent of an area has a positive statistically significant relationship with the number of dams. In all of the estimated equations, however, we can reject the hypothesis that the number of dams increases proportionally to the area (a coefficient of 1), supporting the view that the benefit from additional dams diminishes once the first dam is in place in a region.

The number of downstream subbasins always has a negative coefficient, although this coefficient is weakly significant in only two of the equations. The negative coefficient suggests that dams tend to be in the lower reaches of river basins, all else equal. The slope of the basin has a statistically significant and positive effect in all models except the conditional model in column 5; the pattern suggests an effect on the presence of dams, rather than the number once dams are present. The coefficients on population density suggest that more people increase the likelihood of dams, as well as their number, conditional on the presence of any dam (though the conditional effect may be smaller).

The wetness index has surprising opposite effects in the probit and conditional on positive equations that are both statistically significant.

3.2 Robustness

Table 5 considers several variants on the equations in Table 4. First, we consider two alternative measures of intensity of dam building activity: the total reservoir capacity and the total height of dams in the subbasin country area.¹⁷ The estimated coefficients with these new dependent variables are similar to those for the counts of dams: the presence of a different downstream country in the basin raises the intensity of dams. The coefficients are only weakly statistically significant for both measures.

Column 3 of Table 5 returns to using the count of all dams, but excludes areas with no downstream subbasins. These areas are on a coast and can never constitute a shared water resource, by our definition. Without these coastal areas, the point estimate on the presence of a downstream country remains similar in magnitude but is only weakly significant. The coefficient on the count of downstream basins rises to very nearly zero with these coastal areas excluded, so the tendency we observe for dams to be placed in downstream areas seems to be explained by a higher density of dams near the coast.¹⁸

¹⁷ Both measures are sums of the respective values across all dams in the subbasin-country area. The GRanD project calculated reservoir capacity, so these data are available for all but a handful of dams. By contrast, the dam heights are missing for 7% of the dams. These missing heights are treated as zero as a conservative assumption. Reservoir capacity has a very dramatic upper tail, so a few observations may be very influential in these equations.

¹⁸ Some dams lie on the border between two countries and thus the two countries must coordinate to exploit the resource. With our coding system, areas where rivers form the border will almost always be coded as having a different country downstream. If free riding is less likely on border rivers because of the need for cooperation in dam construction, the presence of dams on border rivers will therefore introduce a conservative bias into our estimates of the extent of free riding.

Column 4 of Table 5 reports estimates from a Poisson regression, as an alternative to the main OLS models.¹⁹ Poisson regression provides a theoretically-consistent approach to the zeros in the dependent variable. The sample size in column 4 is smaller than in the main OLS equations in Table 4 because the Poisson model drops observations from GRDC basins with few observations (about 23% of the full sample) to allow it to converge. The coefficient on the presence of a downstream country in the Poisson model is positive, significant at 1%, and much larger than those from the OLS models, suggesting that resource-sharing increases dam construction by about 89%.²⁰ In sum, the main model results in Table 4 are qualitatively robust to the alternative specifications in Table 5.

4. Extensions

This section presents several extensions to the main models. First, we differentiate among dams by use. Second, we address the role of institutions in possibly mitigating free riding, by controlling for funding by a multilateral institution and for the presence of transboundary water management institutions.

4.1 Categories of use

Our method does not allow us to isolate border rivers because our observations are watersheds, including not only the border river, but also its tributaries, which are not likely to be on borders. However, by excluding all subbasins that lie in multiple countries, we can exclude border rivers (along with a number of other types of subbasins). This exclusion reduces the number of subbasins by about 30% and results in estimates of the coefficient on downstream countries that are positive and somewhat smaller than the values in Table 4, and not statistically significant. However, these estimates are not especially informative given the need to exclude many relevant areas from the analysis.

¹⁹ The dam counts in our data range from 0 to 83, so the density may not truly be Poisson. But the Poisson estimator is still the pseudo- or quasi -maximum likelihood estimator. To address convergence issues, we use the pseudo-maximum likelihood technique by Santos Silva and Tenreiro (2010), implemented as *ppml* in Stata.

²⁰ The Poisson IRR is calculated as: $100 * [e^\beta - 1]$. If we estimate the basic OLS model on the Poisson sample, results change little in comparison to column 1 of Table 4. Thus, the increase in the estimated effect cannot be attributed to different samples.

Table 6 conducts the analyses for different types of dam because they may differ in their downstream costs. First, in column 1, the equations are estimates on the sum of the irrigation, hydroelectric, and water supply dams only. These dam types may all impose obvious negative externalities on downstream areas. In contrast, dams constructed primarily for flood control could potentially be managed to the benefit of downstream areas. The parameter estimates in column 1 are quite similar in magnitude to those in Table 4 on all dams. These uses account for 63 percent of all dams in our analysis (see Table 1) and 79 percent of the dams for which any use is reported. Thus, it may not be surprising that this dependent variable produces similar estimates to the count of all dams.

The remaining columns of Table 6 repeat the basic equation separately for the four most common categories of use: irrigation, hydroelectricity, water supply, and flood control. We expect all but the last to impose significant burdens on downstream areas, all else equal. The point estimates of the coefficients on the presence of a downstream country are smaller in magnitude for each of the categories separately, although positive. The downstream country coefficient is statistically significant at the 5% level only for water supply dams; these dams involve the most consumptive use and thus may pass the greatest share of their costs downstream. Although flood control benefits occur downstream of dams, we do not find a negative coefficient for this variable; perhaps the benefits are too localized for such an effect to manifest when the downstream country may be a great distance away. For columns 2 through 5 in Table 6, data limitations are concern: when the analysis is restricted to one type of dam (and all dams with missing use category data are thrown out), many basins have zero dams and contribute little information to the analysis.

4.2 Dams funded by multilateral institutions

When agencies external to riparian countries — such as multilateral financial institutions — fund dam construction, these agencies may take regional impacts into account and thus be less susceptible to

common property problems. To address this possibility, we remove dams that received funding from the World Bank from the equations. Information on the World Bank funding of dams comes from the non-governmental organization International Rivers; we matched their lists of dams that received World Bank funding from 1948 through 1999 to the GRanD data by the name of the dam.²¹

Columns 1 and 2 of Table 7 report results from re-estimating equation (1), dropping dams that received World Bank funding between 1948 and 1999 from the dam counts in the dependent variable.²² Column 1 considers all dams and column 2 the large dams that are systematically included in the GRanD data and likely to be priorities for World Bank financing. The results differ little from those in the basic model in Table 4, suggesting that external funding source does not significantly influence the common resource problem.

4.3 International water resource management institutions

Countries aim to use international water resource management institutions, such as treaties, to replace regimes of resource conflict with cooperation. In this subsection, we provide some evidence on the success of these institutions. In particular, we examine whether the presence of a water treaty pertaining to a given international river basin limits the degree of free riding.

The Transboundary Freshwater Dispute Database (TFDD) project at Oregon State University has compiled more than 400 international, freshwater-related agreements, dating from 1820 to 2007 (TFDD,

²¹ International Rivers produced a hardcopy list of dams receiving funding from the World Bank between 1948 and 1994 (Sklar and McCully 1994) and provided us with an Excel file for dams funded between 1994 and 1999. We thank Aviva Imhof at International Rivers for her assistance in obtaining these data.

²² Dams constructed with World Bank funds between 1999 and 2005 are not identified in our dataset, but we expect the effect of this omission to be small.

2014).²³ We matched TFDD's river basin codes to the GRDC river basin codes to associate treaties with our observations at the river basin level.

We interact the presence of the treaty with the presence of a downstream country to see if the presence of agreements reduces free riding. The estimated equation is equation (2):

$$\log(Dams_{ij}) = \beta_1 C_{ij} + \beta_2 C_{ij} M_k + \gamma X_{ij} + \alpha_i + u_k + \epsilon_{ij} \quad (2)$$

in which M_k is a binary variable indicating whether an international water management treaty is in effect in the GRDC basin in which the area is located and the interaction term is $C_{ij} M_k$. We cannot identify a separate effect of the treaty on dam counts because any such effect is absorbed by the river basin dummy, u_k .

Columns 3 and 4 of Table 7 report estimates of equation (2). In column 3, all dams are used. In column 4, the dams are restricted to the dams with large reservoirs. The coefficients of interest in these equations are not statistically significant. The coefficient on the treaty interaction has an unexpected positive sign: rather than reducing the tendency to find more dams in areas upstream of borders, the point estimate would suggest an increase in dams upstream of other countries in the presence of a treaty.

One possible explanation of the counterintuitive point estimates in columns 3 and 4 is that water management treaties are endogenous. They may be more likely to emerge in watersheds that are valuable to more than one country (especially where resources are scarce); dams may also be more likely in such watersheds. Alternatively, institutions may arise specifically to support dam construction,

²³ See: <http://www.transboundarywaters.orst.edu>.

or after dams have been constructed and conflict has developed between countries sharing a watershed. Any of these sources of endogeneity would bias the coefficients in equation (2).

In Table 8, we address the possibility of endogenous water management institutions using instrumental variables. Column 1 repeats the OLS results from column 3 of Table 7, for comparison. In columns 2 and 4, we report results from two-stage least squares (2SLS) models with different sets of excluded instruments; columns 3 and 5 report first-stage results. The dependent variable in the first stage is the interaction of the endogenous treaty variable with the dummy for the presence of a downstream country. In the first stage, this interaction is regressed on the instruments and the exogenous variables from the main equation. Because the first stage equations also include the country and basin effects, country-level or basin-level instruments are interacted with the downstream country dummy.

Our first instrument is a Herfindahl-like index of population within a GRDC basin, representing the degree of concentration among countries within a basin (equal to 1 for single-country basins). Prior research suggests that the more control any single country has over a basin, the less likely it is to participate in a basin management treaty (Espey and Towfique 2004); distribution of power within a basin appears to be an important driver of treaty formation more generally (Zawahri and Mitchell 2011). We instrument for the interaction between treaty and downstream country with the interaction of *HHI population* and *downstream country* in column 2. The magnitude of the downstream country coefficient estimate increases dramatically, and the sign of the instrumented treaty interaction is consistent with the hypothesis that treaties mitigate free-riding, but neither coefficient is statistically significant.²⁴ In

²⁴ We also obtained data from the TFDD on treaty purpose. If we restrict the treaties variable to count only treaties that specifically mention the management of water allocation (water quantity), the results are qualitatively the same – a positive coefficient on the presence of a downstream country, a negative coefficient on

column 3, the first-stage regression results are consistent with Espey and Towfique (2004): population concentration has a negative and significant effect on treaty formation. The small F-statistic from the first stage is consistent with weak instruments in this just-identified model.²⁵

We then add five additional instruments to the model. In column 4, we include two variables describing a country's membership in conventional international organizations. Strong trade ties and other such links are correlated with treaty formation (Espey and Towfique 2004, Zawahri and Mitchell 2011).²⁶ The instruments are counts of the number of global organizations and of multiregional organizations in which the country was a member during the period 1952-97. The Center for Systemic Peace (Marshall *et al.* 1999) classifies the organizations and provides data on membership. Another pair of instruments describes historical forms of governance and political participation. We use country-level historical averages (1940-2013) of the weighted autocracy index and the weighted democracy index from the Polity IV database of the Center for Systemic Peace (Marshall *et al.* 2013).²⁷ Although these characteristics may drive treaty formation, we do not have strong priors on the direction of this correlation: democratic regimes may be more likely to cooperate, as is often posited, but autocratic regimes may find it easier to conclude agreements without popular support. Finally, we add an

the interaction between downstream country and a treaty, similar magnitudes for the two coefficients, and neither is significantly different from zero.

²⁵ A cluster-robust Anderson-Rubin-Wald test fails to reject the null hypothesis that the overidentifying restrictions are valid.

²⁶ If water treaties and membership in other international agreements both formalize an underlying propensity to cooperate, however, the exclusion restriction might be problematic for our equations.

²⁷ Both indices capture competitiveness of political participation, openness/competitiveness of recruitment of the chief executive, and constraints on the chief executive. The autocracy index also captures regulation of political participation. Because distinct elements of autocratic and democratic authority may co-exist in a single regime, the two indices enter our model as separate instruments (Marshall *et al.* 2013).

instrument to capture income disparities among countries sharing a basin – the basin-level coefficient of variation of GDP in 2009.

Column 4 reports results from a 2SLS regression using all six instruments. The signs of the downstream country and treaty interaction coefficients are consistent with our hypotheses, but statistically insignificant; they vary little in comparison to the single-instrument model in column 2. The cluster-robust first-stage F-statistic remains small, suggesting weak instruments, although it is slightly improved with the additional instruments.²⁸

We repeat the models in Table 8 using limited-information maximum likelihood (LIML) estimation instead of 2SLS; LIML may perform better than 2SLS in the presence of weak instruments (Hahn et al. 2004). The results are qualitatively similar to Table 8: the coefficient on downstream country is positive, the coefficient on the interaction between treaty and downstream country is negative, and neither is statistically significant, for any combination of the instruments.

The question of whether treaties can mitigate free-riding in water diversion and impoundment in international river basins is a difficult one to answer econometrically. Of the 382 major river basins in our analyses, we code 116 as international and thus eligible for a treaty. Eighty basins have at least one international river management treaty, and 48 basins have at least one such treaty that explicitly addresses water allocation.²⁹ We exploit all available global data in the analysis, but the amount of

²⁸ An Anderson-Rubin-Wald test of the validity of overidentifying restrictions rejects the null hypothesis in column 4 – additional evidence that the instruments are weak.

²⁹ Of the 80 basins with treaties, 8 are not coded as international by our methods. Visual inspection suggests that 7 of these basins are not international, so the functions of these treaties are unclear. For the remaining basin, the geographic extent of the GRDC basin and TFDD basins differ. In any event, these 8 treaties do not influence our results because the treaty variable only appears interacted with the “some downstream country” dummy.

identifying variation is necessarily small. Thus, even stronger instruments might not produce more precise results.

5. Conclusion

This paper investigates whether countries consider the welfare of other nations that share water resources when they make water development decisions. The results suggest that countries engage in more intensive dam construction in areas that are upstream of international borders than other areas, all else equal. Thus, the ability to export some costs of dams may incentivize their construction in international river basins. Our evidence on the role of international water management institutions in mitigating these incentives is inconclusive. The failure to confirm statistically a mitigating effect of treaties may partly reflect difficulties in finding exogenous sources of variation to use as instrumental variables. It may also stem from fundamental limitations of the data: there are fewer than 300 international river basins around the globe that are candidates for treaties, limiting the possible identification to differences across fairly small groups.

The evidence that countries do typically take advantage of opportunities to free ride in water development decisions has several implications. First, it suggests sub-optimality in dam locations that should be considered by economists and policy makers who evaluate these projects. Second, it suggests that Coasean bargaining cannot be relied upon to resolve problems from such international spillovers in practice. Water in rivers should present a relatively straightforward problem, with a small number of countries sharing a well-defined resource and a natural default allocation of property rights to the upstream country. Our results do not support optimism about the likelihood of cooperation over more complex or global resources.

References

- Baum, C. F., M. E. Schaffer, and S. Stillman. 2007. Ivar2: Stata module for extended instrumental variables/2SLS, GMM and AC/HAC, LIML, and k-class regression. Boston College Department of Economics, Statistical Software Components S425401. Downloadable from <http://ideas.repec.org/c/boc/bocode/s425401.html>.
- Becker, Nir, and K. William Easter. 1999. Conflict and cooperation in managing international water resources such as the Great Lakes. *Land Economics*. 75:233-245.
- Bernauer, Thomas and Patrick M. Kuhn. 2010. Is there an environmental version of the Kantian Peace? Insights from water pollution in Europe. *European Journal of International Relations*, 16(1): 77-102.
- Cai, H.B., Y. Chen and G. Qing. 2013. Polluting thy neighbor: The case of river pollution in China, Peking University working paper.
- Center for International Earth Science Information Network (CIESIN), Centro Internacional de Agricultura Tropical (CIAT). 2005. *Gridded Population of the World, Version 3 (GPWv3) Data Collection*. Palisades, NY: Columbia University. <http://sedac.ciesin.columbia.edu/gpw/index.jsp>
- Collier, Michael, Robert H. Webb, and John C. Schmidt. 2000. *Dams and Rivers: A Primer on the Downstream Effects of Dams*. United States Geological Survey Circular 1126. Denver, CO: U.S. Geological Survey.
- Dinar, Shlomi. 2008. *International Water Treaties: Negotiation and Cooperation along Transboundary Rivers*. London: Routledge.
- Dinar, Ariel, Brian Blankespoor, Shlomi Dinar, and Pradeep Kurukulasuriya. 2010. Does precipitation and runoff variability affect treaty cooperation between states sharing international bilateral rivers? *Ecological Economics* 69: 2568–2581.
- Duflo, Esther and Rohini Pande. 2007. Dams. *Quarterly Journal of Economics* 122(2): 601-646.
- Eckstein, Otto. 1965. *Water resource development: the economics of project evaluation*. Cambridge, MA: Harvard University Press.
- Espey, Molly, and Basman Towfique. 2004. International bilateral water treaty formation. *Water Resources Research* 40, W05S05, doi:10.1029/2003WR002534.
- Fekete, Balázs M., Charles J. Vörösmarty, and Wolfgang Grabs. 2002. High-resolution fields of global runoff combining observed river discharge and simulated water balances. *Global Biogeochemical Cycles*, 16(3): 15-1-15-10.

- Frisvold, George B., and Margriet F. Caswell. 2000. Transboundary water management: game-theoretic lessons for projects on the US-Mexico border. *Agricultural Economics* 24: 101-111.
- Gisser, Micha, and David A. Sanchez. 1980. Competition versus optimal control in groundwater pumping. *Water Resources Research*. 16:638-642.
- Gleick, Peter H. 1993. Water and conflict: fresh water resources and international security. *International Security* 18(1): 79-112.
- Gray, Wayne and Ronald J. Shadbegian. 2004. 'Optimal' pollution abatement: Whose benefits matter, and how much? *Journal of Environmental Economics and Management* 47: 510–534.
- Global Runoff Data Centre. 2007. *Major River Basins of the World*. GRDC in the Bundesanstalt fuer Gewaesserkunde, 56068 Koblenz, Germany. Available at: <http://grdc.bafg.de>.
- Hahn, J., J. Hausman, and G. Kuersteiner. 2004. Estimation with weak instruments: accuracy of higher-order bias and MSE approximations. *Econometrics Journal* 7: 272-306.
- Harpman, David A. 1999. Assessing the short-run economic cost of environmental constraints on hydropower operations at Glen Canyon Dam. *Land Economics* 75(3): 390-401.
- Holland, Stephen P., and Michael R. Moore. 2003. Cadillac Desert revisited: Property rights, public policy and water-resource depletion. *Journal of Environmental Economics and Management*. 46:131-155.
- International Rivers. 2010. New online map plots 140 large dams planned for the Amazon. Press release. 18 August. Available at: <http://www.internationalrivers.org/2010-8-17/new-online-map-plots-140-large-dams-planned-amazon>.
- Kahn, Matthew E., Pei Li, Daxuan Zhao. 2103. Pollution Control Effort at China's River Borders: When Does Free Riding Cease? NBER Working Paper 19620.
- Lipscomb, Molly, and Ahmed Mushfiq Mobarak. 2013. Decentralization and pollution spillovers: evidence from the re-drawing of county borders in Brazil. Working Paper, Batten School of Public Policy, University of Virginia, Charlottesville, VA.
- Lehner, B., C. Reidy Liermann, C. Revenga, C. Vorosmarty, B. Fekete, P. Crouzet, P. Doll, M. Endejan, K. Frenken, J. Magome, C. Nilsson, J.C. Robertson, R. Rodel, N. Sindorf, and D. Wisser. 2011. *Global Reservoir and Dam Database, Version 1 (GRanDv1): Dams, Revision 01*. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). Available at: <http://sedac.ciesin.columbia.edu/data/set/grand-v1-dams-rev01>.
- Marshall, Monty G., Donna F. Ramsey Marshall, and Sherry Marie Young. 1999. *Memberships in Conventional Intergovernmental Organizations, 1952-1997*. Vienna, VA: Center for Systemic Peace.

- Marshall, Monty G., Ted Robert Gurr, and Keith Jagers. 2013. *Polity IV Project: Political regime characteristics and transitions, 1800-2013*. Dataset users manual. Vienna, VA: Center for Systemic Peace.
- Postel, Sandra L., and Aaron T. Wolf. 2001. Dehydrating conflict. *Foreign Policy*. September/October: 60-67.
- Richter, Brian D., Sandra Postel, Carmen Revenga, Thayer Scudder, Bernhard Lehner, Allegra Churchill, and Morgan Chow. 2010. Lost in development's shadow: The downstream human consequences of dams. *Water Alternatives* 3(2): 14-42.
- Rogers, Peter. 1969. A game theory approach to the problems of international river basins. *Water Resources Research*. 5:749-760.
- Scudder, Thayer. 2006. *The Future of Large Dams: Dealing with Social, Environmental, Institutional and Political Costs*. London: Earthscan.
- Sigman, Hilary. 2002. International spillovers and water quality in rivers: Do countries free ride? *American Economic Review*. 92:1152-1159.
- Sigman, Hilary. 2005. Transboundary spillovers and decentralization of environmental policies, *Journal of Environmental Economics and Management* 50: 82–101.
- Santos Silva, J. M. C., and S. Tenreyro. 2010. On the existence of the maximum likelihood estimates in Poisson regression. *Economics Letters* 107: 310-312.
- Sklar, Leonard, and Patrick McCully. 1994. *Damming the Rivers: The World Bank's Lending for Large Dams*. International Rivers Network Working Paper No. 5. Berkeley, CA.
- Song, Jennifer and Dale Whittington. 2004. Why have some countries on international rivers been successful negotiating treaties? A global perspective. *Water Resources Research* 40, W05S06, doi:10.1029/2003WR002536.
- Strobl, Eric, and Robert O. Strobl. 2011. The distributional impact of large dams: evidence from cropland productivity in Africa. *Journal of Development Economics* 96: 432-450.
- Strzepek, Kenneth M., Gary W. Yohe, Richard S. J. Tol, and Mark W. Rosegrant. 2008. The value of the high Aswan Dam to the Egyptian economy. *Ecological Economics* 66: 117-126.
- Transboundary Freshwater Dispute Database (TFDD), Department of Geosciences, Oregon State University. <http://www.transboundarywaters.orst.edu> (Last accessed: March 1, 2014).
- U.S. Geological Survey (USGS). 2012. HYDRO1k Elevation Derivative Database. Available at: <http://eros.usgs.gov/>.

- Verdin, K.L, and J. P. Verdin. 1999. A topological system for delineation and codification of the Earth's river basins. *Journal of Hydrology* 218: 1–12.
- Weidmann, N. B., D. Kuse, and K. S. Gleditsch. 2010. The geography of the international system: The CShapes dataset. *International Interactions* 36(1).
- Wolf, Aaron. 1998. Conflict and cooperation along international waterways. *Water Policy* 1 (2): 251–265.
- Wolf, Aaron T., Jeffrey A. Natharius, Jeffrey J. Danielson, Brian S. Ward, and Jan K. Pender. 1999. International river basins of the world. *International Journal of Water Resources Development* 15(4): 387-427.
- World Commission on Dams. 2000. *Dams and Development: A new framework for decision-making*. London: Earthscan.
- Zawahri, Neda A., and Sara McLaughlin Mitchell. 2011. Fragmented governance of international rivers: negotiating bilateral versus multilateral treaties. *International Studies Quarterly* 55: 835-858.

Table 1. Areas and dams by continent, 2005 cross-section

	Africa	Asia	Australasia	Europe	North America	South America	Total
Areas							
Subbasin-country areas	712	654	81	498	610	425	2958
Pfafstetter level 3 subbasins	478	513	54	317	545	369	2276
GRDC river basins	54	73	18	73	107	59	384
Dams							
All dams in analysis	542	1209	109	796	1813	227	4696
Large-reservoir dams	126	574	38	334	814	185	2071
Irrigation, water supply, or hydroelectric dams	413	671	97	649	1047	88	2965
World Bank funded	27	45	0	28	13	43	156

Table 2: Main uses of dams in GRanD

	All GRanD Dams		GRanD Dams in GRDC Basins	
	Number	Share	Number	Share
Irrigation	1,781	25.95	1,376	29.30
Missing	1,577	22.98	788	16.78
Hydroelectricity	1,541	22.46	1,055	22.47
Water supply	847	12.34	527	11.22
Flood control	547	7.97	473	10.07
Recreation	293	4.27	254	5.41
Other	206	3.00	162	3.45
Navigation	56	0.82	51	1.09
Fisheries	14	0.20	10	0.21
Total	6,862	100.00	4,696	100.00

Notes: A few dams also have major or secondary uses indicated, but most do not. Use category “other” includes dams with primary uses of livestock watering and water pollution control, in addition to those labeled in GRanD as “other”.

Table 3: Summary statistics, by presence of downstream countries

	No downstream country	Some downstream country	Total
Number of dams	1.854 (6.526)	1.134 (3.832)	1.599 (5.728)
Some dam present	0.260 (0.439)	0.236 (0.425)	0.252 (0.434)
Number of large dams	0.878 (3.027)	0.397 (1.305)	0.707 (2.563)
Number of irrigation, water supply, or hydro dams	1.109 (4.237)	0.798 (2.862)	0.999 (3.809)
Some downstream country	0 (0)	1 (0)	0.355 (0.478)
Number of downstream countries	0 (0)	1.852 (1.193)	0.657 (1.136)
Subbasin-country area in sq km	30302.1 (66440.5)	23765.7 (34684.7)	27984.8 (57313.6)
Number of downstream subbasins	3.676 (4.901)	8.188 (5.593)	5.275 (5.590)
Mean wetness index in subbasin	6.262 (1.190)	6.509 (1.272)	6.349 (1.225)
Mean slope in subbasin	1.438 (1.598)	1.325 (1.704)	1.398 (1.637)
Population density (/sq km) in 2000 in subbasin	45.32	49.33	46.74
Observations (subbasin-country areas)	1,859	1,021	2,880

Means, with standard deviations in parentheses for observations used in regression analysis.

Table 4: OLS and Probit estimates for number and presence of dams

	(1) All dams	(2) Large dams	(3) All dams	(4) Probit (Dams>0)	(5) Dams>0
Some downstream country	0.263* (0.112)	0.179+ (0.101)	0.263* (0.113)	0.286+ (0.168)	0.407** (0.152)
Log(num. of downstream countries)			-0.00176 (0.0963)		
Log(subbasin area)	0.369** (0.0559)	0.295** (0.0490)	0.369** (0.0559)	0.702** (0.0537)	0.553** (0.0604)
Log(num. of downstream subbasins)	-0.0471+ (0.0262)	-0.0410 (0.0253)	-0.0471+ (0.0264)	-0.0446 (0.0530)	-0.0268 (0.0353)
Log(average slope)	0.184** (0.0676)	0.187** (0.0590)	0.184** (0.0676)	0.560** (0.127)	-0.0632 (0.0749)
Log(wetness index)	0.421 (0.373)	0.331 (0.351)	0.421 (0.373)	1.477* (0.666)	-1.329** (0.448)
Log(population density)	0.165** (0.0352)	0.134** (0.0365)	0.165** (0.0353)	0.279** (0.0761)	0.124* (0.0580)
R^2	0.335	0.273	0.335		0.575
Major river basins	382	382	382	117	237
Observations	2880	2880	2880	2158	725

+ $p < .10$, * $p < .05$, ** $p < .01$

Includes dummies for all countries and river basins. Standard errors in parentheses clustered by river basin. Except in column (4), all dependent variables are counts of dams in logs.

Table 5: Alternative dependent variables and other robustness checks

	(1) Total reservoir capacity	(2) Total dam height	(3) Only upstream areas	(4) Poisson
Some downstream country	0.496 ⁺ (0.300)	0.417 ⁺ (0.217)	0.207 ⁺ (0.123)	0.635 ^{**} (0.147)
Log(subbasin area)	0.944 ^{**} (0.121)	0.667 ^{**} (0.0907)	0.348 ^{**} (0.0713)	0.942 ^{**} (0.0730)
Log(num. of downstream subbasins)	-0.128 ⁺ (0.0728)	-0.0903 ⁺ (0.0528)	-0.00627 (0.0633)	-0.0968 ^{**} (0.0367)
Log(average slope)	0.695 ^{**} (0.202)	0.502 ^{**} (0.162)	0.221 [*] (0.0873)	0.135 (0.117)
Log(wetness index)	1.659 (1.057)	1.019 (0.849)	0.698 (0.485)	-0.189 (0.688)
Log(population density)	0.457 ^{**} (0.107)	0.320 ^{**} (0.0628)	0.151 ^{**} (0.0380)	0.320 ^{**} (0.0818)
R^2	0.262	0.293	0.306	0.831
Major river basins	382	382	119	238
Observations	2880	2880	2186	2217

⁺ $p < .10$, ^{*} $p < .05$, ^{**} $p < .01$

Includes dummies for all countries and river basins. Standard errors in parentheses clustered by river basin. Except Poisson model in column 4, all dependent variables in logs.

Table 6: OLS estimates, by dam type

	(1) Irrig-supply- hydro	(2) Irrigation	(3) Water supply	(4) Hydro-electric	(5) Flood control
Some downstream country	0.230* (0.105)	0.107 (0.0719)	0.111* (0.0510)	0.171 (0.109)	0.106 (0.0709)
Log(subbasin area)	0.302** (0.0461)	0.157** (0.0281)	0.105** (0.0317)	0.162** (0.0250)	0.0902* (0.0404)
Log(num. of downstream subbasins)	-0.0446+ (0.0250)	-0.0103 (0.0170)	-0.0225 (0.0150)	-0.0404+ (0.0208)	-0.0170 (0.0106)
Log(average slope)	0.143+ (0.0811)	0.101+ (0.0602)	0.0418 (0.0350)	0.0301 (0.0545)	0.0251 (0.0293)
Log(wetness index)	0.0815 (0.440)	0.441+ (0.264)	0.0909 (0.150)	-0.480 (0.345)	0.123 (0.100)
Log(population density)	0.109** (0.0334)	0.0359 (0.0309)	0.0461** (0.0174)	0.0593** (0.0180)	0.0170 (0.0135)
R^2	0.293	0.217	0.191	0.200	0.137
Major river basins	382	382	382	382	382
Observations	2880	2880	2880	2880	2880

Includes dummies for all countries and river basins. Standard errors in parentheses clustered by river basin. All dependent variables are counts of dams in logs.

+ $p < .10$, * $p < .05$, ** $p < .01$

Table 7: Estimates accounting for World Bank funding and river basin treaties

	(1) Without WB funding (all dams)	(2) Without WB funding (large dams)	(3) All dams	(4) Large dams
Some downstream country	0.265* (0.111)	0.184+ (0.0995)	0.0330 (0.202)	-0.0109 (0.195)
Some downstream country * some treaty			0.290 (0.219)	0.239 (0.213)
Log(subbasin area)	0.363** (0.0558)	0.288** (0.0488)	0.369** (0.0558)	0.295** (0.0490)
Log(num. of downstream subbasins)	-0.0415 (0.0259)	-0.0343 (0.0250)	-0.0477+ (0.0262)	-0.0415 (0.0254)
Log(average slope)	0.142* (0.0662)	0.156** (0.0571)	0.183** (0.0671)	0.187** (0.0587)
Log(wetness index)	0.364 (0.357)	0.333 (0.343)	0.400 (0.371)	0.313 (0.352)
Log(population density)	0.144** (0.0319)	0.115** (0.0323)	0.163** (0.0344)	0.132** (0.0357)
R^2	0.333	0.267	0.336	0.273
Major river basins	382	382	382	382
Observations	2880	2880	2880	2880

+ $p < .10$, * $p < .05$, ** $p < .01$

Includes dummies for all countries and river basins. Standard errors in parentheses clustered by river basin. All dependent variables are counts of dams in logs.

Table 8: IV estimates of effects of treaties

	(1)	(2)	(3)	(4)	(5)
	OLS	2SLS	First stage	2SLS	First stage
	estimates	HHI	HHI	All instr.	All instr.
Some downstream country	0.0330 (0.218)	1.374 (1.272)	1.030** (0.0497)	1.128 (0.729)	1.613** (0.129)
Treaty * downstream country (endogenous var)	0.290 (0.236)	-1.403 (1.573)		-1.089 (0.831)	
Global agreements * downstream country					-0.0291** (0.00615)
Multiregion agreements * downstream country					0.0467** (0.00767)
HHI population * downstream country			-0.422** (0.0942)		-0.519** (0.104)
autocracy index 1940-2013 * downstream country					-0.0433* (0.0183)
democracy index 1940-2013 * downstream country					-0.0367* (0.0164)
Coeff of variation, GDP per cap (2009) in basin					-0.0710 (0.0819)
Log(subbasin area)	0.369** (0.0601)	0.369** (0.0549)	-0.00001 (0.00162)	0.371** (0.0551)	0.000315 (0.00158)
Log(num. of downstream subbasins)	-0.0477+ (0.0282)	-0.0443+ (0.0260)	0.00132 (0.00212)	-0.0456+ (0.0261)	0.00334+ (0.00188)
Log(average slope)	0.183* (0.0723)	0.187** (0.0711)	-0.0001 (0.0086)	0.183** (0.0697)	0.00126 (0.00842)
Log(wetness index)	0.400 (0.400)	0.524 (0.405)	0.0515 (0.0456)	0.464 (0.396)	0.0704 (0.0452)
Log(population density)	0.163** (0.0371)	0.178** (0.0414)	0.00884** (0.00269)	0.175** (0.0385)	0.00649** (0.00237)
R^2	0.663	0.209	0.956	0.220	0.963
Major river basins	382	382	382	372	372
Observations	2880	2880	2880	2854	2854
First-stage F-statistic		F(1, 381)=2.13 Prob>F=0.145		F(6, 371)=2.98 Prob>F =0.008	

+ $p < .10$, * $p < .05$, ** $p < .01$. Includes dummies for all countries and river basins. Standard errors in parentheses clustered by river basin. Dependent variables in columns 1, 2 and 4 are counts of dams in logs. Dependent variable in columns 3 and 5 is a binary indicator for the presence of a river basin treaty.