Damming the Commons: An Empirical Analysis of International Cooperation and Conflict in Dam Location

Sheila M. Olmstead, Hilary Sigman

Abstract: This paper examines whether countries consider the welfare of other nations when they make water development decisions. We estimate econometric models of the location of major dams around the world as a function of the degree of international sharing of rivers. We find that dams are more prevalent in areas of river basins some distance upstream of foreign countries, supporting the view that countries free ride in exploiting water resources. We find some evidence that international institutions, in particular multinational financing and international water management treaties, may mitigate this free riding.

JEL Codes: Q20, Q25, Q28

Keywords: Common pool, Dams, Free riding, International rivers, Treaties, Water impoundment

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.[1]

Sheila M. Olmstead is at the LBJ School of Public Affairs, University of Texas at Austin, PO Box Y, Stop E2700, Austin, TX 78713 (sheila.olmstead@austin.utexas.edu) and at Resources for the Future (RFF). Hilary Sigman is at the Department of Economics, Rutgers University, 75 Hamilton Street, New Brunswick, NJ 08901 (hsigman@rutgers.edu), RFF, and the National Bureau of Economic Research. We are grateful to Georgia Bush, Ju Young Park, and Sergey Reid for research assistance and to seminar participants at the AERE summer conference, Fordham University, Oregon State University, the University of Texas at Austin, the Property Environment Research Center, and the University of Wisconsin–Madison for comments. This research was partially supported by a grant from the World Bank's Knowledge for Change Program. The views expressed in the paper are ours alone and should not be attributed to the World Bank or its member countries.

1. A "large dam" is 15 or more meters tall, or between 5 and 15 meters with a water storage capacity of at least 3 million cubic meters (Scudder 2006). The United States has

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Large dams have complex welfare implications. Dams provide valuable services to their beneficiaries, including hydropower, irrigation, urban water supply, navigation, and flood control. However, for at least 50 years, economists and others have worried that the benefit-cost analysis methods employed to assess the welfare impacts of dams have overstated benefits and understated costs (Eckstein 1965; Ansar et al. 2014).[2] 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 dams on social welfare within a country and has started to fill this gap (Holland and Moore 2003; Duflo and Pande 2007; 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 empirical literature. Even if countries make efficient decisions about dam construction on domestic rivers, countries sharing a river may overdevelop 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% 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; one between China, Myanmar, and Thailand over China's plans to dam the upstream reaches of the Nu River; and one between three Central Asian states over current and planned dams on regional rivers.[3] Disputes over allocation of shared rivers may escalate with population growth and global climate change, which may increase

more than 6,000 large dams, many of the largest (Hoover, Grand Coulee, Glen Canyon) constructed between 1935 and 1965 (Collier, Webb, and Schmidt 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).

2. 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).

3. On the Ethiopia/Egypt conflict over the Nile, see Witte (2013). On China's plans for Nu River dams, see Jacobs (2013). On Central Asia, see Nurshayeva (2012).

aridity in some regions and increase the 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 river basins around the world to be a function of the degree of international sharing of rivers, controlling for other factors, including country and river-basin fixed effects. Our basic model tests the hypothesis that countries are more likely to build dams 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. In some equations, the effect is weaker when the area is immediately upstream of the border; near the border, some of the benefits of the dam may accrue to the downstream country, which reduces the extent to which the spillover improves the cost-benefit calculus for the upstream country. We find some suggestive evidence that multilateral financing and international treaties might reduce the extent of free riding.

The structure of the paper is as follows. Section 1 briefly reviews the previous literature that considers dam placement and transboundary spillovers in rivers, as well as the potential mitigating impacts of international agreements. Section 2 introduces the basic econometric model. Section 3 describes the sources of our data and the GIS analysis conducted to generate our variables of interest. Section 4 presents the results of our main equations and robustness checks. Section 5 considers several extensions, including analyses that break down results by type of dam and consider the role of international water management institutions. Section 6 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 US 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.

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, Chen, and Qing, forthcoming; Kahn, Li, and Zhao, forthcoming). Similarly, water pollution emissions by US 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.[4] 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 (Harpman 1999; Richter et al. 2010; Stone 2011). Thus, when countries consider the perceived benefits and costs of constructing a dam in a given location, they are more likely to find the project desirable where an international border makes some of these downstream costs less salient. We do not argue that countries seek locations that export costs but rather that they are more likely to go ahead with projects where apparent costs are reduced by being partially borne by downstream countries.

Some types of dams can also generate positive downstream externalities. For example, flood control dams may have positive impacts on flood risk mitigation that extend to a downstream country. If countries fail to internalize all such externalities, then these types of dams might be underprovided in upstream areas of international basins.

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

4. 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. That research design raises the possibility of strategic, or at least unrepresentative, positioning of monitors, whereas we are able to work with a universe of locations.

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, Sandler, and Sargent 1997; Beron, Murdoch, and Vijverberg 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. BASIC MODEL

We model the count and presence of dams in an area as a function of the sharing of a water resource and other characteristics that may affect the benefits and costs of dams in a location. We must define observations at the level of a geographic area (rather than at the dam level, for example) because we do not observe potential dam sites, only the geographic distribution of those sites chosen for construction.

Observations are defined at the level of a subbasin-country area: the intersection between a hydrologically determined "subbasin" of a major river basin and a country. A subbasin is the drainage area for a portion of the main stem of a river or for a tributary of the main river. The subbasin is a natural choice for the unit of area for our analysis because our main variables depend on which areas are downstream of the observation and thus are uniform within a subbasin. When a subbasin spans multiple countries, we divide the areas into separate observations by country to focus on a single country's decisions about dam placement.

The basic econometric model is equation (1):

$$\log\left(Dams_{ij}\right) = \beta C_{ij} + \gamma \log X_{ij} + \alpha_i + u_k + \varepsilon_{ij}, \tag{1}$$

in which $Dams_{ij}$ is the count of dams in the portion of country i that lies within river subbasin j, C_{ij} is one or more measures of international resource sharing, 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.[5] We also consider two

5. To allow areas with no dams to remain in the analysis, 0.1 was added to all dam counts before taking logs. In table 5, we present Poisson estimates without this transforma-

alternative dependent variables—the total size of impounded reservoirs and total dam height. Robustness checks and extensions are discussed in sections 4 and 5.

Inclusion of the river basin effects, u_k, means that the resource-sharing coefficient, β, is identified only by variation within a major river basin; it does not compare international and domestic basins. The country effects, α_i, substitute for many of the socioeconomic variables that might otherwise be included in such an equation.

Standard errors, ε_{ij}, are clustered at the river basin level to address concerns about spatial heterogeneity. 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.

3. DATA

We use Geographic Information System (GIS) software to create the dependent variables, measures of resource sharing, and other explanatory variables. The HYDRO1k data set from the US Geological Survey (USGS) defines subbasins of each river basin, using global elevation data (USGS 2012). HYDRO1k codes subbasins with 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 six digits. We rely on the three-digit subbasin level as our basic unit of observation for tractability.[6] These subbasins vary in size depending on the structure of river systems but have a median area of 15,400 square kilometers (an area about half the size of Belgium) in our data.

The Pfafstetter system codes subbasins in a way that makes it possible to identify upstream-downstream relationships among subbasins and thus is the basis of our count of downstream countries. To facilitate this determination, we restrict the area studied to the 405 major river basins of the world identified by the Global Runoff Data Centre (GRDC 2007).[7] Almost all international river basins are included

tion and, in table 4, probit and conditional-on-positive regressions do not depend upon it. These alternative specifications suggest that results are not sensitive to this transformation.

6. 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 three-digit subbasin in HYDRO1k.

7. This restriction was necessary because not all the areas coded with the same first digit by the Pfafstetter identifier share a river mouth. 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. By adding the GRDC information, we were able to separate basins based on unique mouths.

among these major river basins, so this restriction does not much affect the identification of the impact of water-resource sharing.[8]

Our 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. The first three rows in table 1 describe the distribution of subbasin-country areas, subbasins, and major river basins across continents in 2005.[9]

To construct the dependent variables, we placed dams in subbasin-country areas using the Global Reservoir and Dams (GRanD) data set, which 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 0.1 km^3 and a number of dams with smaller reservoirs. We use a total of 4,594 (just over two-thirds) of the dams described in the GRanD data because we restrict our analysis to dams in major river basins.[10] GRanD provides some information on the characteristics of the dams that we use 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; unfortunately, the data lack information on use for 23% of dams. The second panel of columns in table 2 describes the distribution of dam types, considering only the dams included in our analysis. Although the fraction of dams missing information on use is smaller, the overall distribution of types is similar to the full GRanD data set. Our data set has a slightly higher share of irrigation dams and small differences in the share 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 in our analysis. First, it reports the counts of dams by continent, showing that North America has the highest number. Because GRanD provides the universe

8. 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. One more basin is dropped for lack of flow accumulation and downstream distance data (because flow accumulation is too low to appear in the HYDRO1k Streamlines files), leaving 381 major river basins in our analysis.

9. The country borders are those in effect in 2005 according to CShapes (Weidmann, Kuse, and Gleditsch 2010), which provides spatial data on country borders over time.

10. Maps illustrating the subbasin country areas, locations of dams, and our resource-sharing variable by continent are in an appendix, available online.

Table 1. Areas and Dams by Continent

	Africa	Asia	Australia/ Oceania	Europe	North America	South America	Total
Areas:							
Subbasin-country areas	600	624	54	467	581	399	2,725
Pfafstetter level 3 subbasins	427	500	50	310	526	350	2,163
Major river basins	53	73	18	72	107	59	381
Dams:							
All dams in analysis	525	1,208	34	792	1,808	227	4,594
Large-reservoir dams	122	573	7	334	813	185	2,034
Irrigation, water supply, hydroelectric dams	397	670	25	648	1,043	88	2,871
World Bank–funded dams	27	45	0	28	13	43	156

Table 2. Main Uses of Dams

	All GRanD Dams		Dams Used in Analysis	
	Number	Percentage	Number	Percentage
Irrigation	1,781	25.95	1,320	28.73
Missing	1,580	23.02	787	17.13
Hydroelectricity	1,541	22.46	1,040	22.64
Water supply	847	12.34	504	10.97
Flood control	547	7.97	469	10.21
Recreation	293	4.27	252	5.49
Other	206	3.00	161	3.50
Navigation	56	.82	51	1.11
Fisheries	14	.20	10	.22
Total	6,862	100.00	4,594	100.00

Note.—This table indicates the "main use." A few dams also have major or secondary uses indicated but most do not. Use category "other" includes dams with main uses of livestock watering and water pollution control, in addition to those labeled in GRanD as "other."

only of dams with reservoirs greater than 0.1 km^3 and a potentially nonrandom selection of dams on smaller reservoirs, we also report some analyses that include only the dams with large reservoirs; 2,034 dams have these large reservoirs, 44% of the 4,594 used in the analysis. 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 2,871 dams (or 62% 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 Oceania) received this funding.

Our key explanatory variables are the presence and number of countries downstream of each subbasin-country area.[11] We use the upstream-downstream re-

11. The country borders (and thus the measures of resource sharing) are based on 2005 data. Although borders may change over time, most of the dams in our data (71%) were built in the post–World War II period, during which borders have been stable (and many of the earlier dams are in North America, where borders have been even more stable). Further, 66% of the dams in Africa and 75% of the dams in South America were built after 1960. Using the CShapes data, we examined the effects of changes in borders since 1960 on our downstream country count variable; during this time, the only changes resulted from the breakup of the Soviet Union and the separation of Namibia from South Africa. No dams were built in any of the areas that experienced a change in downstream country count. Thus,

lationships embedded in the Pfafstetter coding to identify the subbasins that are downstream from each subbasin-country area and check whether any of these downstream subbasins are in a different country.[12]

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. As table 3 reports, areas upstream of an international border have fewer dams, less total reservoir capacity, and lower dam height than other areas. The raw means differ in the opposite of the direction expected with free riding, but, as discussed below, the two types of areas differ systematically in other ways as well.

Table 3 also reports our principal resource-sharing variables. The basic variable, the presence of some downstream foreign country, is positive for 36% of the observations. For those observations, the average number of downstream countries is less than two.

In addition, table 3 shows a variable that reflects proximity to the downstream country; it is a dummy variable that equals one if the subbasin is immediately upstream of a subbasin in a different country. Far upstream of a border, the upstream country receives all the benefits of the dam but experiences only a share of the costs, with the remainder of the costs borne by the downstream country. Near the border, however, the upstream country may receive only a share of the benefits. Thus, the incentive to place dams just upstream of the border is weaker than elsewhere upstream. Most of the upstream observations (58%) are immediately upstream of the downstream country.

Turning to the additional covariates, we include several variables to capture the location of the subbasin-country area in the river system. If dams are simply more likely to be located either upstream or downstream in a major river basin, such a tendency might otherwise confound the indicator we use for shared resources. The first variable we include to deal with this potential issue is the number of downstream subbasins, regardless of whether they are in the same country or a different

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the use of the modern borders does not greatly affect the analysis. In addition, we unfortunately cannot exploit time-series variation to estimate the effects of interest with these data because there is no change in the dependent variable.

12. Research on transboundary spillovers in water pollution has usually used distance to the border as the measure of resource sharing. We do not use this metric for several reasons. First, our unit of observation is the entire area, not a specific pollution-monitoring station; we would have to use an average distance for all areas in the basin which might poorly represent the true distance from any of the dams in an area. Second, it is technically difficult to calculate these distances. Finally, for the costs associated with water diversion, a major aspect of potential free riding, it will not matter whether the diversion occurs far upstream or closer to the downstream country: in either case, the downstream country is deprived of that water.

one. To create our principal resource-sharing variable, we search this set of subbasins to see if any of them are in a different country. The number of downstream subbasins is thus associated with the likelihood of finding a different downstream country. As table 3 reports, areas with a downstream country have on average twice as many downstream subbasins as other areas. However, this difference in means overstates the difference between the two distributions. For areas with a small number of downstream subbasins (which are the most common in the data), the representation of observations with some downstream country is similar to the sample as a whole; for example, 43% of observations with one downstream subbasin and 42% of observations with two downstream subbasins have a different country downstream. Therefore, observations with downstream countries are well represented in the lower reaches of rivers.

In addition to the count of downstream subbasins, we include two other measures to control for the location of the subbasin-country area within the river system. One measure is the "flow accumulation," which measures the catchment area that is upstream of a given point (in thousands of square kilometers). The variable included in our equations is the maximum flow accumulation in the subbasin-country area because points on the main stem of the river are the most likely locations for dams; flow accumulation along many smaller streams in the area is unlikely to be relevant. A second location measure is the downstream distance to the ocean or other (internal) sink calculated along the river's path. We use the average downstream distance within the subbasin-country area. Both of these variables are calculated for each subbasin-country area from HYDRO1k's Streamlines files. The difference in means reported in table 3 again indicates that areas upstream of an international border are typically further upstream in the river basin, with lower flow accumulation and higher downstream flow distance to the mouth.

We also include several measures of the physical suitability and need for dams in a subbasin-country area. The size of each subbasin-country area (in km^2) addresses the likelihood that larger areas will contain more dams. We control for slope, since areas with higher slope present better opportunities for dam construction (especially for hydroelectric dams). 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 six-digit subbasins in each

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

Table 3. Summary Statistics, by Presence of Downstream Countries

	No Downstream Country (1)	Some Downstream Country (2)	Total (3)
Number of dams	1.980	1.176**	1.686
	(6.748)	(3.875)	(5.875)
Some dam present	.272	.250	.264
	(.445)	(.433)	(.441)
Number of large dams	.936	.418**	.746
	(3.129)	(1.324)	(2.629)
Number of irrigation, water supply, or hydroelectric dams	1.184	.826*	1.054
	(4.383)	(2.896)	(3.909)
Total reservoir capacity	2,317.7	1,457.6+	2,003.3
	(11,665.8)	(10,239.7)	(11,171.5)
Total dam height	83.02	44.16**	68.82
	(300.7)	(158.3)	(258.6)
Some downstream country	0	1	.366
	(0)	(0)	(.482)
Number of downstream countries	0	1.809	.661
	(0)	(1.184)	(1.128)
Next downstream subbasin in different country	0	.577	.211
	(0)	(.494)	(.408)
Number of downstream subbasins	3.870	7.997**	5.379
	(4.976)	(5.700)	(5.615)
Max flow accumulation in area (1,000 km^2)	156,153	62,793**	122,030
	(473,963)	(168,778)	(393,612)
Mean downstream flow length in area (km)	799.0	1,733.0**	1,140.4
	(813.0)	(1,112.9)	(1,036.4)
Subbasin-country area (km^2)	30,494	27,828	29,519
	(62,476)	(51,002)	(58,548)
Mean wetness index in subbasin	6.243	6.492**	6.334
	(1.169)	(1.259)	(1.208)
Mean slope in subbasin	1.424	1.362	1.401
	(1.540)	(1.757)	(1.623)

Table 3 (*Continued*)

	No Downstream Country (1)	Some Downstream Country (2)	Total (3)
Population density/km^2 (2000) in area	46.21	48.42	47.02
	(160.0)	(94.48)	(139.6)
Observations (subbasin-country areas)	1,729	996	2,725

Note.—Means, with standard deviations in parentheses, for observations used in regression analysis. Asterisks in column 2 indicate significant difference in means between the two groups, according to *t*-test for difference in means.

$^+$ $p < .10$.

* $p < .05$.

** $p < .01$.

of the three-digit Pfafstetter subbasins.[14] As another measure of demand for dam services, we calculated 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).

4. RESULTS

4.1. Main Results

Column 1 of table 4 reports ordinary least squares (OLS) estimates of the coefficients in equation (1). The coefficient on the presence of a different country downstream is positive and statistically significant. The point estimate of this coefficient, .242, suggests 27% more dams in subbasins where water is shared with another country than in those where it is not.[15] In column 2 of table 4, the measure of resource sharing is broadened: in addition to the presence of a downstream country, the equation in

14. In previous versions of the equations, we also included historical precipitation in the subbasin-country area, calculated from gridded data on precipitation from 1950 through 2000 (Fekete, Vörösmarty, and Grabs 2002). The estimated coefficients on local historical precipitation were small and statistically insignificant in all equations and are not currently shown in the tables. Dams thus do not appear to be either a substitute or complement for rainfall, once we control for basin and country effects and other covariates.

15. Estimates of the percentage change in response to the dummy explanatory variable here and below use the formula, $100(\exp(\beta^* - .5v\beta^*) - 1)$, where β^* is the estimated coefficient and $v\beta^*$ is its estimated variance (Kennedy 1981).

Table 4. OLS and Probit Estimates for Number and Presence of Dams

	OLS (1)	OLS (2)	OLS (3)	Probit (4)	OLS Dams > 0 (5)
Some downstream country	.242*	.249*	.265*	.455*	.274
	(.111)	(.111)	(.121)	(.217)	(.182)
Next downstream subbasin in different country			−.0354	−.381**	.0611
			(.0690)	(.103)	(.117)
Log(no. of downstream countries)		−.0856			
		(.105)			
Log(subbasin area)	.391**	.391**	.390**	.647**	.578**
	(.0703)	(.0703)	(.0706)	(.0595)	(.0622)
Log(no. of downstream subbasins)	−.0336	−.0316	−.0337	−.0590	.0102
	(.0276)	(.0280)	(.0276)	(.0558)	(.0549)
Log(flow accumulation)	.0136	.0138	.0136	.0820*	−.0292
	(.0196)	(.0195)	(.0197)	(.0365)	(.0205)
Log(downstream distance)	.0192	.0194	.0187	.0712	−.0619
	(.0319)	(.0320)	(.0321)	(.0626)	(.0512)
Log(average slope)	.186**	.187**	.188**	.588**	−.0828
	(.0716)	(.0717)	(.0711)	(.134)	(.0739)
Log(wetness index)	.429	.433	.440	1.461*	−1.355**
	(.420)	(.420)	(.419)	(.725)	(.441)
Log(population density)	.172**	.171**	.172**	.280**	.125*
	(.0367)	(.0367)	(.0366)	(.0792)	(.0626)
Country effects	Yes	Yes	Yes	Yes	Yes
River basin effects	Yes	Yes	Yes	Yes	Yes
R^2	.334	.334	.334		.573
Number of river basins	381	381	381	105	237
Observations	2,725	2,725	2,725	2,025	719

Note.—Standard errors in parentheses clustered by river basin. Except in col. 4, all dependent variables are counts of dams in logs.

$^{+}$ $p < .10$.

* $p < .05$.

** $p < .01$

column 2 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 is relatively unchanged, 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.[16]

Column 3 of table 4 adds another covariate, a dummy variable that equals one for areas upstream of an international border and for which the next downstream subbasin is at least partially across the closest country border. As noted earlier, this variable may help control for potential heterogeneity in the extent of resource sharing. In locations near the border, the downstream country may experience some of the benefits, as well as the costs, of the dam; this sharing of benefits might offset the discounting of the downstream country's costs and make dams less likely near the downstream border than further upstream. The coefficient on the main resource-sharing variable in this model increases slightly relative to columns 1 and 2. The coefficient on the variable indicating direct hydrologic proximity to a foreign subbasin is small, negative, and insignificant. The net effect is the sum of the two coefficients, so the results in column 3 continue to suggest free riding in all upstream regions, with no statistically significant difference near the border. In later models, this measure of border proximity does appear to have interesting implications; thus we retain it for now. Unless indicated, results are qualitatively robust to its exclusion.

Columns 4 and 5 of table 4 consider alternative functional forms for the relationship between dam counts and the presence of a downstream country. 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.[17] The coefficient on the presence of a foreign country downstream is positive in both these equations, statistically significant at 5% in the probit equation, but not statistically significant ($p = .13$) in the conditional-on-positive OLS. The

16. 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 introduce a conservative bias into our estimates of the extent of free riding.

Our method does not allow us to isolate border rivers because our observations are watersheds, including not only the river, but also surrounding areas and tributaries; if the river is the border, the subbasin will straddle it. 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, 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.

17. In the conditional-on-positive model in column 5, dam counts revert to their true value (in logs), rather than adding 0.1, as is done before taking logs in the other models.

point estimate in column 5 suggests that the count of dams conditional on the presence of dams may be similarly sensitive to resource sharing as the unconditional count (.274 vs. .242). The probit marginal effect suggests a 7.5% increase in the likelihood of at least one dam upstream of international borders. In this model, direct proximity to the downstream country reduces, but does not eliminate, the incentive to dam shared rivers; dams are still statistically significantly more prevalent directly upstream of the border than in domestic subbasins, but their prevalence is lower than further upstream in the basins.

In addition to the coefficients of the variables reflecting resource sharing, several other variables enter the equations with statistically significant coefficients. Not surprisingly, the size 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), suggesting that the benefit from additional dams may diminish once the first dam is in place.

We do not find much evidence to support the hypothesis that dams are typically placed either upstream or downstream in the river system. The number of downstream subbasins generally has a negative coefficient, but the coefficient is not statistically significant in any equation.[18] The maximum flow accumulation in the subbasin has mostly positive point estimates, as expected, but is only statistically significant in the probit equation. The downstream distance from the subbasin-country area is similarly insignificant. Taken together, these estimates suggest a weak tendency for dams to be in the lower reaches of river basins, all else equal; such a tendency, if not fully controlled in our equations, would produce a conservative bias in our estimates of the extent of free riding (because free riding occurs upstream). But the estimates do not suggest that this effect is strong enough to be a major concern.

The slope of the basin has a statistically significant and positive effect in all models except the conditional model in column 5; the pattern indicates 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 and their number conditional on the presence of any dam (although 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.

18. To allow nonlinearity in the relationship, we also estimated the equations with a series of dummy variables for the number (and ranges, for higher values) of downstream subbasin count. Although the coefficients on the dummies were negative and jointly significantly different than the excluded category (no downstream subbasins), the coefficient on the downstream country variable is the same as in column 1 of table 4, and no particular pattern appears in the coefficients of the dummies.

Table 5. Alternative Dependent Variables and Other Robustness Issues

	Total Reservoir Capacity (1)	Total Dam Height (2)	Only Large Dams (3)	Only Upstream Areas (4)	Poisson (5)
Some downstream country	.731* (.344)	.494* (.241)	.209+ (.109)	.238+ (.132)	.834** (.210)
Next downstream subbasin in different country	−.374+ (.209)	−.153 (.138)	−.0503 (.0784)	−.0215 (.074)	−.388* (.192)
R^2	.259	.290	.270	.589	.835
Number of river basins	381	381	381	118	238
Observations	2,725	2,725	2,725	2,099	2,112

Note.—Models include country and river basin effects, as well as all additional covariates in table 4 main models (natural logs of: subbasin area, number of downstream subbasins, flow accumulation, downstream distance, average slope, wetness index, and population density). Standard errors in parentheses clustered by river basin. All dependent variables in logs, except Poisson model in col. 5.

+ $p < .10$.

* $p < .05$.

** $p < .01$.

4.2. Additional Specifications

Table 5 considers several variants on the equations in table 4, reporting only the main coefficients of interest. 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.[19] 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 damming activity, with the coefficient on the downstream country variable positive and significant at .05 in both regressions. The estimates in column 1 suggest that the total capacity of dammed reservoirs nearly doubles (increases by 96%) when an area is upstream of an international border, though this effect is reduced (to a 36% increase) when the border crosses the very next downstream subbasin. The column 2 estimates suggest

19. 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.

that total dam height increases by about 59% in areas upstream of other countries; there is no significant mitigating effect on dam height of direct hydrological proximity to the downstream country, although the estimated coefficient is negative. As in the probit model in table 4, these results suggest that free riding occurs but that it is less pronounced when the downstream neighbor is very close; close to the border, transboundary spillovers may reduce both domestic costs and benefits.

Column 3 of table 5 considers only dams with reservoir capacity greater than .1 km^3. As mentioned earlier, the GRanD project geocoded all dams with reservoirs of this size and provided information on some dams with smaller reservoirs, when information was available. Column 3 includes only the larger dams (44% of the dams in the sample) to address potential concern about nonrandom selection of smaller dams. When only large-reservoir dams are considered, the coefficient on the presence of a downstream country falls slightly (.209 vs. .265 in table 4) and is only weakly significant. This decline may be due to nonrandom selection of the smaller dams into the GRanD database that is correlated with our main variable. For example, these dams may be more likely to be included by researchers if they are in international basins, which may receive more attention than domestic basins. However, the point estimate might also be smaller because the location of very large dams is more constrained by physical geography and thus less sensitive to common pool problems.

Column 4 of table 5 returns to using the count of all dams but excludes areas with no downstream subbasins. The excluded areas are on a coast or an inland sink. The reason for excluding these areas is that our main measures of resource sharing can never be positive for these areas: our variables are formed by looking at all subbasins downstream from the current basin and indicating if any of these subbasins are in a different country. Given that these areas are not "at risk" for having a downstream country, column 4 provides an alternative definition of the comparison group. The point estimate on the presence of a downstream country remains about the same as in the basic equations in table 4 and is weakly statistically significant, even though the sample size shrinks considerably. These results lend support to the view that our results are not driven by the position of the subbasin in the river system but rather by transboundary spillovers.

Column 5 of table 5 reports estimates from a Poisson regression, as an alternative to the main OLS models.[20] Poisson regression provides a theoretically consistent approach to the zeros in the dependent variable. The sample size in column 5 is smaller than in the main OLS equations in table 4 because the Poisson model drops observations from major river basins with few observations (about 23% of the full

20. 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 Tenreyro (2010), implemented as *ppml* in Stata.

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. The Poisson coefficients suggest that resource sharing more than doubles the number of dams constructed upstream of international borders but increases it by a smaller 83% when the area is immediately upstream of a foreign subbasin.[21]

The results of these robustness checks generally support the main results in table 4. Dam counts, reservoir size, and dam height all increase when an area is upstream of an international border, all else equal. Neither restricting the analysis to the universe of large dams nor considering only upstream areas appreciably affects the main results. The Poisson results suggest a larger impact of resource sharing on damming activity. To be conservative, and to preserve the appealing robustness properties of OLS, we move to extensions, keeping equation (1) as the main model.

5. 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 examining dams funded by a multilateral institution (the World Bank) and by controlling for the presence of transboundary water management treaties.

5.1. Categories of Use

Table 6 conducts the analyses separately by type of dam because dam types may differ in their downstream costs. First, in column 1, the dependent variable is the sum of 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 almost identical to the results for all dams in table 4. These uses account for 62% of all dams in our analysis (see table 1) and 75% of the sample 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 main or major use: irrigation, hydroelectricity, water supply, and flood control. We expect all but the last to impose significant burdens on downstream areas. In each of these models, data limitations are a concern: when the analysis is restricted to one type of dam (and all dams with missing use category data are thrown out), many major river basins have zero dams and thus do not contribute

21. The Poisson IRR is calculated as: $100 \times [e^{\beta} - 1]$. If we estimate the basic OLS model from table 4 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. OLS Estimates, by Dam Type

	Irrig-Supply-Hydro (1)	Irrigation (2)	Water Supply (3)	Hydroelectric (4)	Flood Control (5)
Some downstream country	.246*	.136	−.0095	.171^{+}	.0754
	(.123)	(.113)	(.0632)	(.0989)	(.0676)
Next downstream subbasin in different country	−.0482	−.0683	.145*	.0172	.0900*
	(.0829)	(.0693)	(.0612)	(.0665)	(.0401)
R^2	.294	.237	.201	.193	.157
Percentage of international basins with some dams	74%	38%	33%	64%	17%

Note.—All equations have 381 rivers basins and 2,725 observations. Models include country and river basin effects, as well as all additional covariates in table 4 main models (natural logs of: subbasin area, number of downstream subbasins, flow accumulation, downstream distance, average slope, wetness index, and population density). Standard errors in parentheses clustered by river basin. All dependent variables are counts of dams in logs.

$^{+}$ $p < .10$.

* $p < .05$.

** $p < .01$.

to the identification of the resource-sharing effect in equations that include basin fixed effects. To indicate the identification issues, the final row in table 6 reports the share of international basins that have some dams: for some rare categories of dams, especially flood control dams, identification rests on few major river basins, and thus the results are noisy and not definitive.

The results vary across the different dam types. For irrigation dams, neither coefficient of interest is statistically significant. The downstream country coefficient is statistically significant at 10% for hydroelectric dams. Water supply dam counts increase by about 15% in areas just above a foreign subbasin. This pattern differs from the pattern observed in the probit results for all dams in table 4, where areas just upstream of the border were less likely to have dams. Urban water supply may not follow this pattern because it is the most consumptive dam use in our analysis and it does not require gravitational flow through downstream canals (unlike irrigation). As a result, an upstream country may capture all the benefits of a water supply dam that is very close to the border.

The results for flood control dams are similar to the results for water supply dams: about 9% more flood control dams are constructed in areas for which the next downstream subbasin is at least partially in another country. This result is surprising because flood control benefits accrue exclusively downstream. The results in column 5 could indicate cooperative water development.[22] Alternatively, they may result from the fact that even dams with flood control indicated as a principal or major use of the dam also have other uses with downstream costs. Finally, only a few international river basins have variation in the number of flood control dams (because most basins have zero flood control dams), so the surprising result may just be due to data limitations.

5.2. 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 reestimate the basic model, counting only dams that received funding from the World Bank between 1948 and 1999 in the dependent variable. Information on the World Bank funding of dams comes from the nongovernmental 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.[23]

Column 1 of table 7 reports results from this analysis.[24] The effect of resource sharing on the count of dams indicates that resource sharing increases damming activity by about 10.7%, which is a smaller effect than in the comparable model for all dams in table 4 (coefficient estimate of .102 vs. .265). Interestingly, for World Bank–funded dams, this effect is reduced to a 4% increase in areas directly upstream of the first subbasin in another country. Taken together, these results sug-

22. If we drop the 45% of observations in river basins in which a treaty explicitly addresses water allocation, the water supply dam estimates more closely resemble the results for all dams (the coefficient on the presence of a downstream country is positive and significant, and that on the variable indicating direct hydrologic proximity to a neighboring country is not significantly different from zero). If we do the same for the flood control dam equation, neither coefficient is significant. We formally address the possibility of treaties' influence on free riding in section 5.3.

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

24. As an alternative, we have also estimated a model in which we remove the 156 World Bank–funded dams from the dam counts, but not surprisingly, removing a small number of dams from the sample does not result in estimates that differ significantly from those reported for all dams in columns 1 and 3 of table 4.

Table 7. Estimates Accounting for World Bank Funding and River Basin Treaties

	WB Dams OLS (1)	All Dams OLS (2)	All Dams 2SLS (3)	All Treaties First Stage (4)	All Dams 2SLS (5)	Water Quant Treaties First Stage (6)
Some downstream country	.102**	–.006	1.301+	1.703**	.642+	1.562**
	(.0354)	(.217)	(.692)	(.241)	(.352)	(.294)
Next downstream subbasin in	–.0649+					
different country	(.0380)					
Some downstream country × Some treaty		.316	–1.338+			
(endogenous var)		(.229)	(.770)			
Some downstream country × Water					–.584	
allocation treaty (endogenous var)					(.455)	
Some downstream country ×				–.540*		–.575*
Population concentration index				(.232)		(.276)
Some downstream country ×				–.0312*		–.0379*
Global agreements				(.0158)		(.0151)
Some downstream country ×				.0514*		.0619**
Multiregion agreements				(.0254)		(.0237)

Some downstream country ×				−.0591⁺		−.0596
Autocracy index				(.0355)		(.0372)
Some downstream country ×				−.0465		−.0242
Democracy index				(.0308)		(.0347)
R^2	.160	.334	.207	.883	.220	.838
Number of subbasins	381	381	373	373	373	373
Observations	2,725	2,725	2,702	2,702	2,702	2,702
First-stage cluster-robust F-statistic for excluded instruments (5, 372)				2.99 (p = .012)		5.29 (p = .000)

Note.—All equations also include country and river basin effects, as well as all additional covariates in table 4 main models (natural logs of: subbasin area, number of downstream subbasins, flow accumulation, downstream distance, average slope, wetness index, and population density). Counts of dams are in logs. The first stages in cols. 4 and 6 predict the interaction of the treaty variable and the downstream country dummy. Standard errors in parentheses are clustered by river basin.

$^{+}$ $p < .10$.

* $p < .05$.

** $p < .01$.

gest that dams with multilateral funding may be less subject to common property problems than those funded using exclusively domestic resources. It is not clear, however, whether the World Bank actually reduces free riding or whether it selects dam projects that cause low international conflict from among many possible projects.

5.3. 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 2014).[25] 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):

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

in which M_k is a binary variable indicating whether an international water management treaty is in effect in the river 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 effect, u_k.

Column 2 of table 7 reports OLS estimates for equation (2). 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 column 2 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, countries may enter treaties specifically to support dam construction or to address conflict that has developed after dams have been constructed. Any of these sources of endogeneity would bias the coefficients in equation (2).

25. See http://www.transboundarywaters.orst.edu.

We address the possibility of endogenous water management institutions using instrumental variables (IV) estimated by two-stage least squares (2SLS) in columns 3–6 of table 7 (Baum, Schaffer, and Stillman 2007). We use two different treaty variables in the IV models: (1) a dummy variable indicating the presence of any water management treaties in the river basin, as we used in the OLS model in column 2 of table 7, and (2) a more restrictive dummy indicating the presence of any water management treaties that specifically mention water allocation. 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.

The IV models employ five instruments. The first instrument, a Herfindahl-like index of population within a river basin, represents the degree of population concentration among countries within a basin (equal to one 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 also appears to be an important driver of treaty formation (Zawahri and Mitchell 2011). Two additional instruments describe a country's membership in conventional international organizations because 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, Marshall, and Young 1999) classifies the organizations and provides data on membership. A final 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, Gurr, and Jaggers 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.

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 coexist in a single regime, the two indices enter our model as separate instruments (Marshall et al. 2013).

The first-stage results for the IV model using the broader treaty definition (any water management treaty), and those for the model using the more restrictive treaty variable (counting only treaties specifically focused on water allocation) are reported in columns 4 and 6, respectively. The first-stage results support the findings from the literature reported earlier. Consistent with Espey and Towfique (2004), population concentration has a negative and significant effect on treaty formation. We also see the expected positive association between water treaties and membership in multiregional organizations, but a surprising negative association with membership in global organizations. A higher autocracy index is weakly negatively associated with treaty formation in a basin in column 4.

Columns 3 and 5 report second-stage results for the IV models using the five instruments. In both the "any treaty" and "any water allocation treaty" models, the resource-sharing coefficient is positive and the interaction of sharing with presence of a river basin treaty is negative. The absolute magnitudes of the estimates are approximately the same in both models, suggesting that countries tend to free ride, but that this incentive may be just about counterbalanced by treaty constraints. However, the estimates are only suggestive of this pattern: the coefficients are statistically significant only at 10%, the treaty interaction is insignificant in the "any water allocation treaty" model, and the cluster-robust first-stage *F*-statistics for the excluded instruments are small, which suggests that the instruments are weak.[28]

Although the IV models suggest that treaties may almost offset the tendency to place dams upstream of borders, these results are equivocal. Indeed, econometric analysis may not be able to provide definitive evidence about the effects of treaties because of the fundamentally small sample of international river basins. Of the 381 major river basins in our analyses, we code 115 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 identifying

28. Because of the concern about weak instruments, we reestimated the models in columns 3 and 5 using limited-information maximum likelihood (LIML) estimation instead of 2SLS; LIML may perform better than 2SLS in the presence of weak instruments (Hahn, Hausman, and Kuersteiner 2004). The LIML estimates were nearly identical in terms of the point estimates and their precision to those presented in the table.

29. Of the 80 basins with treaties, eight are not coded as international by our methods. Visual inspection suggests that seven of these basins are not international, so the functions of these treaties are unclear. For the remaining basin, the geographic extent of the GRDC-defined basin and TFDD-defined basin differ. These eight treaties do not influence our results because the treaty variable only appears interacted with the "some downstream country" dummy.

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

6. 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 some distance upstream of international borders than other areas, all else equal. Thus, the ability to export some costs of dams may create incentives for their construction in upstream areas of international river basins. The increase in damming activity in these basins appears when looking at dam counts, as well as at the size of impounded reservoirs and the total height of dams.

Our evidence on the role of international institutions in mitigating these incentives is less conclusive. We do find that dams funded by the World Bank may be less subject to the common property problems in international basins, although we cannot separate a causal impact of World Bank funding from a selection effect. The estimates also provide weak support for a mitigating effect of river basin treaties. The inconclusive results regarding the impacts of treaties may partly reflect difficulties in finding exogenous sources of variation to use as instrumental variables. But it may also stem from fundamental limitations of the data: only the few international river basins around the globe 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 suboptimality in dam locations that should be considered by economists and policy makers who evaluate these projects. Second, the finding that free riding occurs on average in the data suggests that Coasean bargaining cannot always be relied upon to resolve problems from such international spillovers in practice. Water in rivers should present a relatively straightforward coordination 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.

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