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The Impact of Water Supply Variability on Treaty Cooperation between International Bilateral River Basin Riparian States

Ariel Dinar
Brian Blankespoor
Shlomi Dinar
Pradeep Kurukulasuriya

The World Bank
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Environment and Energy Team
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Abstract

This paper assesses the impact of water supply variability on treaty cooperation between international bilateral river basin riparian states. Climate change is anticipated to change the variability of water supply, as well as its expected magnitude. Previous studies have focused mainly on water scarcity, measured in terms of mean precipitation or per capita water availability in the country, as a trigger for conflict or cooperation. The water variability measure used here captures both annual runoff variability and precipitation variability over periods of 30 and 100 years. The analysis used economic and international relations data to identify incentives for international cooperation in addressing water supply variability. The authors find that small-to-moderate increases in variability create an impetus for cooperation, although large increases in variability would reduce incentives for treaty cooperation. Stronger diplomatic and trade relations support cooperation, while uneven economic power inhibits cooperation. Various measures of democracy/governance suggest different impacts on cooperation across the basin riparians. The findings have policy implications in the context of preparedness for impacts of climate change on the water sector.

This paper—a product of the Environment and Energy Team, Development Research Group—is part of a larger effort in the department to mainstream research on climate change. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at bblankespoor@worldbank.org.

The Impact of Water Supply Variability on Treaty Cooperation between International Bilateral River Basin Riparian States[1]

Ariel Dinar, University of California, Riverside (adinar@ucr.edu)
Brian Blankespoor, World Bank, Washington DC (bblankespoor@worldbank.org)
Shlomi Dinar, Florida International University, Miami (dinars@fiu.edu)
Pradeep Kurukulasuriya, United Nations Development Program, New York (pradeep.kurukulasuriya@undp.org)

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1. Introduction

Scientists are confident now that the "global average net effect of climate since 1750 has been one of warming" (IPCC, 2007:3), and that "[A]t continental, regional and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones" (IPCC, 2007:7).

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) suggests that "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising of global average sea levels. The 100-year linear trend (1906-2005) of 0.74 [0.56 to 0.92] °C is larger than the corresponding trend of 0.6 [0.4 to 0.8] °C (1901-2000) given in the Third Assessment Report" (IPCC, 2007:1-10).

These higher world temperatures are expected to increase the hydrological cycle activity, leading to a change in precipitation patterns and increase in evapotranspiration. More specifically, climate change is expected to increase heat, reduce/increase precipitation, and also increase water supply variability both intra- and inter-annually. "There is high confidence that by mid-century, annual river runoff and water availability are projected to increase at high latitudes (and in some tropical wet areas) and decrease in some dry regions in the mid-latitudes and tropics. There is also high confidence that many semi-arid areas (e.g. Mediterranean basin, western United States, southern Africa and northeast Brazil) will suffer a decrease in water resources due to climate change" (IPCC 2007b:8). The Fourth Assessment Report further verifies the findings from the Third Assessment Report that states: "One major implication of climate change for agreements between competing users (within a region or upstream versus downstream) is that allocating rights in absolute terms may lead to further disputes in years to come when the total absolute amount of water available may be different." (IPCC, 2001: Section 4.7.3).

Some studies assert that climate change can lead to conflict between states who share international bodies of water following the likely dwindling water supplies (Gleditsch et al

2007). On the other hand, several publications suggest that further exacerbation in the water situation may even open the door to new water allocation opportunities between these riparians (ESCAP 1997), and others (e.g., Dinar S., 2009 and the literature he cites) are more specific, suggesting that water scarcity is actually an impetus for cooperation, following a hill shaped relationship between scarcity and cooperation.

Several economic studies analyze, using a general framework, river sharing agreements with deterministic water flows (Ambec and Sprumont, 2002; Ambec and Ehlers 2008). The impact of different water availability levels on stability of cooperation is assessed, using different approaches. Beard and McDonald (2007) assess the consistency of water allocation agreements over time if negotiations are held periodically with known river flow prior to the negotiation. Janmatt and Ruijs (2007), in a stylized model of two regions, wet and arid, suggest that storage could mitigate water scarcity, if upstream and downstream riparian countries find a beneficial allocation to sustain it. They find that the collaboration potential is greater in arid than in wet regions, but that there is little scope for capturing the gains from basin level management if economic integration does not extend beyond water issues. Another work (Ansink and Ruijs, 2008) introduces the effects of climate change on both the efficiency and stability of water allocation agreements in international basins. Using a game theoretic framework it is shown that a decrease in mean flow of a river decreases the stability of an agreement while an increase in variance may have both positive and negative effects on treaty stability.

Others introduce water supply variability into their analysis of specific case studies. Abbink et al. (2005) apply an experimental economics framework to the case of the Syr Darya (Aral Sea Basin) conflict in order to evaluate various governance structures and allocation rules needed for enhanced cooperation among Kyrgyzstan, Uzbekistan, and Kazakhstan under several water supply regimes. The conclusion reached by Abbink et al. (2009) is that under the tested water availability values and the proposed payoff schemes, it is not likely that cooperation can be reached in that basin.

Existing studies either address the impact of water scarcity on treaty cooperation, or the effects of water variability in the context of a very specific case study. Studies of international water cooperation focus mainly on water scarcity as a trigger for either conflict or cooperation (e.g., Dinar S. et al. 2007; Hamner 2008; Dinar S. 2009; Tir and Ackerman, 2009; Hensel and

Brochman 2009). As such, various measures of water scarcity, mainly static ones, have been used to assess the emergence of international water treaties and levels of cooperation among riparians. But in order to assess the likely impact of climate change on the stability of existing treaties and on the future likelihood of conflict and cooperation, one may need a water availability measure, such as increased water variability, that can better infer climate change impacts.

Following a series of statements by world leaders in the popular press that worn us of looming wars over water due to increased water scarcity and climate change impact (e.g., BBC 2003; Timesonline 2007), Barnaby has argued that:

> *…it is still important that the popular myth of water wars somehow be dispelled once and for all. This will not only stop unsettling and incorrect predictions of international conflict over water. It will also discourage a certain public resignation that climate change will bring war, and focus attention instead on what politicians can do to avoid it. …And it would help to convince that …the solutions to water scarcity and security lie outside the water sector in the water/food/trade/economic development nexus*
>
> Barnaby (2009:283).

It is, therefore, the Barnaby paper and the sometimes sensationalist water-wars statements, that make-up the general motivation for this paper—to strengthen the scientific basis to our understanding of water-climate change and cooperation/conflict interactions.

In the proceeding sections we introduce water supply variability into a global analysis of treaty formation. Building on existing theories (e.g., Ambec and Dinar A., 2009; Dinar S., 2009), a global dataset of bilateral rivers will be used along with several water variability measures, to assess the likelihood of treaty formation, and treaty cooperation, using the range of climate during the years where existing treaties were signed.[i] In a second stage, using various future climate change predictions, the likelihood of additional treaty formation and cooperation is estimated. Section 2 reviews the scientific basis for the climate-hydrology relationship that affects the flow regime in river basins. Section 3 develops the analytical framework. Section 4 reports the data sources and the construction of the various variables. Section 5 discusses the hypotheses. Section 6 presents the empirical models. The results are presented in Section 7, and the paper concludes in Section 8 with suggested policy implications.

2. Climate, Hydrology, and Flow Regimes in Rivers

The hydrology of river basins is affected by changes in climatic conditions. Anthropogenic-induced climate change is expected to influence water resource cycles significantly. However, the stochastic nature of the changes in the water cycle is uncertain. A useful explanation of the interaction between climate change and the hydrological cycle can be found in Miller and Yates (2005). They suggest that global climate change is expected to alter the hydrologic cycle by affecting the amount, intensity, and temporal distribution of precipitation. Warmer temperatures will affect the amount of winter precipitation in the form of rain or snow, the amount stored as snow and ice, and its melting dynamics. Long-term climatic trends could trigger vegetation changes that would alter a region's water balance. In forest areas, the combination of warmer temperatures and drying soils caused by snow melting earlier than usual or longer droughts can lead to more frequent and extensive wildfires. When this occurs, land cover and watershed runoff characteristics may change quickly and dramatically as wildfires reduce forest cover and thereby affect the runoff response. Less dramatic, but equally important, changes in runoff can affect transpiration of plants, altered by changes in soil moisture availability, as well as plant responses to elevated CO2 concentrations. In addition, changes in the quantity and quality of water percolating to groundwater will result in changes in aquifer levels and quality, in base flows entering surface streams, and in seepage losses from surface water bodies to the groundwater system (Miller and Yates 2005:37).

A comprehensive assessment of available water hydrology-climate studies from around the world is provided in IPCC (1996a, b) and IPCC (2001). The findings in IPCC (2001:Section 4.3.6.1) suggest that:

> *"In general, the patterns found are consistent with those identified for precipitation: Runoff tends to increase where precipitation has increased and decrease where it has fallen over the past few years. Flows have increased in recent years in many parts of the United States, for example, with the greatest increases in low flows …[]. Variations in flow from year to year have been found*

to be much more strongly related to precipitation changes than to temperature changes …[]. There are some more subtle patterns, however. In large parts of eastern Europe, European Russia, central Canada …[], and California …[], a major—and unprecedented—shift in stream flow from spring to winter has been associated not only with a change in precipitation totals but more particularly with a rise in temperature: Precipitation has fallen as rain, rather than snow, and therefore has reached rivers more rapidly than before. In cold regions, such as northern Siberia and northern Canada, a recent increase in temperature has had little effect on flow timing because precipitation continues to fall as snow …[].”

IPCC (2001:Section 4.3.6.1)

However, the IPCC (2001:Section 4.3.6.1) concludes that:

“…it is very difficult to identify trends in the available hydrological data, for several reasons. Records tend to be short, and many data sets come from catchments with a long history of human intervention. Variability over time in hydrological behavior is very high, particularly in drier environments, and detection of any signal is difficult. Variability arising from low-frequency climatic rhythms is increasingly recognized, and researchers looking for trends need to correct for these patterns. Finally, land-use and other changes are continuing in many catchments, with effects that may outweigh any climatic trends.”

(2001:Section 4.3.6.1)

Specifically, not all river basins are affected by climate in the same way. Differences have been observed both within a given country or even a state. (Miller, Bashford and Strem (2006), for example, study 6 basins in Central-Northern California. While the trend of the impact of the various future climate scenarios on the 6 water systems is similar, it is evident that the six basins are different in their level of sensitivity to the same expected changes in temperature and precipitation.

A comparison between 5 international river basins (the Nile, Zambezi, Indus, Mekong, and Uruguay) in Riebsame et al. (2002) suggests that basins in drier regions (e.g., Nile, Zambezi) would be most hydrologically-sensitive to the climate change scenarios that were used in the simulation. Hydrological sensitivity of the Indus and Uruguay basins is described as moderate and that of the Mekong is described as low. The adaptation scenarios that have been considered in the basins include mainly investment in larger storage, and adjustments to allocation regimes. However, because these two adaptation interventions are associated with transboundary property rights, the authors correctly identify that climate change could likely lead to either cooperation or conflict among the basin riparians.

Using simulations, Arora and Boer (2001) analyzed twenty three basins, among them twelve that are international. Applying one climate change scenario they simulated future mean annual discharges and mean annual floods in 2100. Findings suggest that rivers in middle to high latitude are expected to face between +67 and -16 percent change in mean annual discharge and between +68 and -28 percent change in mean annual flood. On the other hand, rivers in tropical and low latitudes are expected to face between +5 and -79 percent change in mean annual discharge and between +26 and -74 percent change in mean annual flow. These findings necessitate a serious consideration of water management adaptation, including a possible adjustment of infrastructure. A recent global study (Palmer et al. 2008) evaluated the future (2050, A2 Scenario) impact of climate change on the discharge of major dammed rivers. The findings are in agreement with Arora and Boer (2001), but much more comprehensive in coverage. They then evaluate a set of river basin management strategies (Bernhardt et al. 2005) to propose a range of interventions that may mitigate future impact of climate change and man-made development on river flow.

Similar findings are suggested by Milly et al (2005), namely an increase of runoff (10-40 percent) by 2050 in high latitude basins in North America and Europe, and in certain low latitude basins such as the La Plata and basins in western Africa. A decrease in runoff between 10 to 30 percent is expected in basins in southern Europe, the Middle East, and basins in mid-latitude western regions of North America and southern Africa.

Climate change is said to affect future river flows by increasing intra and inter-annual variability, and in certain locations to reduce annual means. However, historical records of many river basin flows suggest that significant variability and trends in mean flows have already been observed (Arora et al, 2001; Milly et al. 2005; Palmer et al., 2008; Dinar A., 2009). This means more ‘below average’ and more ‘above average’ precipitation and flow (runoff), which is hard to cope with by riparians that are tied to a given water allocation scheme and existing infrastructure that was designed for a given long-term water flow level. We argue that the various basins in our dataset have already experienced changes in water supply variability (flow, precipitation). Thus, a first stage of analyzing the impact of climate change on the stability of intentional water agreements should focus on observing likely effects of past climate changes on past treaty cooperation. If we can show that water supply variability has affected treaty cooperation in the past 150 years, we would expect that further increase in water supply variability would have similar, or even magnified, effects on treaty cooperation. Therefore, by studying the past changes in climate we will be able to extrapolate predictions how future climates may affect future treaty cooperation. The next section develops the theoretical framework with which we will estimate the impact of change in climate on the likelihood of cooperation among international bilateral river basin riparians.

3. Theory and Hypotheses

Pairs of countries sign treaties over water bodies they share for various reasons. The economics and international relations literature suggest that they do it because they either face difficulties they cannot overcome themselves; or that they anticipate externalities relating to pollution, flood control, or hydropower, (Just and Netanyahu, 1998); or for reasons such as economies of scale where parties anticipate being better off acting in a coalition rather than acting alone when facing certain water scarcity situations (Dinar S., 2009).

The economics and international relations literature that applies statistical tools to international water datasets (Brochmann and Hensel, 2009; Espey and Towfique, 2004; Gleditsch et al., 2006; Hensel et al., 2006; Song and Whittington, 2004; Tir and Ackerman, 2009; Toset et al., 2000; Dinar S., 2009) has gone a long way already in developing a theory that explains various aspects of shared water and environmental treaty making and we adopt a number of these general variables in our study.

Water variability and cooperation

Overall scarcity (or water availability) has become an important explanatory variable in some of these statistical studies. In particular, Dinar, S. 2009 hypothesizes an inverted U-shaped curve between levels of treaty cooperation and water scarcity. When water is not scarce (abundant) riparian states are in less need to cooperate because they boast a sufficient level of water; as scarcity level increases the impetus for cooperation increases. But as water becomes extremely scarce, there is very little to cooperate over and thus formalized treaty formation becomes less likely (Dinar S. 2009, and the literature he cites).

We believe a similar curvilinear relationship may be made in relation to water variability, as the low end of the distribution (low variability) is associated with lower damages and the high end of the distribution (high variability) is associated with significant damages (from droughts and floods, respectively). Consequently, riparians in these situations are hypothesized to exhibit less incidence of cooperation. Cooperation can be reflected in signing new treaties in cases where they do not exist; in more treaties to amend the initial set of agreements; or in new treaties introducing more issues (such as water quantity, hydropower, pollution, and flood control) into the cooperative framework. We use two climatic variables that affect water scarcity, namely basin-level precipitation variability and basin-level runoff variability.

An empirical observation of the mean versus the variability of both precipitation and runoff further strengthens our claim. We find in our data that higher variation is correlated with lower means (R^2=-0.197 and R^2=-0.208 for basin precipitation and for basin runoff, respectively). A similar finding was found in the case of long-term rainfall means and variability in 42 Sub Saharan Countries (Dinar and Keck, 2000).

Democracy and governance

Past studies have concluded that democratic dyads, relative to dyads with at least one non-democracy, are more likely to demonstrate higher international environmental commitment in general and sign international water agreements in particular (Neumayer 2002a; Tir and Ackerman 2009).

In particular, domestic institutions may play a major role in either facilitating or inhibiting international cooperation. Political, legal, and economic institutions sustain the functioning of the state both domestically and internationally. They reflect the state's ability to enter into, and honor, an agreement, which may require financial investments and costs (Congleton, 1992:412-413). Countries that are more institutionally advanced may in turn have little interest in cooperative ventures with countries having weaker and unstable institutions. Similarly, investments are not secure and property rights poorly defined in unstable countries characterized by political turmoil (Deacon, 1994). It is hypothesized therefore that the higher the level of institutionalization and governance (e.g., an effective domestic government) among the riparians, the more a water agreement is likely to be facilitated.

Trade and overall country relations

The literature has also considered other interactions such as trade and the extent of diplomatic ties among the states as additional variables for explaining the emergence or failure of treaty cooperation. By some accounts the more countries trade the higher the level of their interdependence and the higher the likelihood of treaty formation (Polachek 1980, 1987). Janmatt and Ruijs (2007) argue that there is little scope for capturing the gains from basin level management if economic integration does not extend beyond water issues. A history of diplomatic ties and good relations are, therefore, expected to express overall good country relations and increase treaty likelihood (Yoffe et. al. 2003).

Power asymmetries

The international relations literature has entertained power asymmetry as possibly facilitating cooperation (Lowi 1993). Other works have argued that power asymmetry is not necessarily a pre-requisite for cooperation although if asymmetry does exist the hegemon often plays a benign role by facilitating inter-state coordination through incentives (Young 1994; Barrett 2003). Consequently, while brute power may not be relevant for analyzing inter-state cooperation in the case of the environment, the different abilities of countries to provide such incentives as financial transfers or side-payments may be important. Other studies (Just and Netanyahu, 1998:9; Hijri and Grey, 1998: 89) claim that power asymmetries generally impede cooperation. First, a power balance may reflect a type of equality in the sense that a weaker party does not believe it will be taken advantage of by the stronger party, reducing trust issues (Rubin and Brown, 1975:213-233). Second, the more powerful state does not fill obliged to provide costly incentives to encourage the weaker state to cooperate (Bennett, Ragland and Yolles, 1998:63-66). Our economic power variable, measuring the ratio between the more economically powerful and the less powerful riparian is hypothesized to negatively affect treaty cooperation.

Geography

Certain riverine geographical configurations have been said to facilitate conflict while other have been said to be more conducive to cooperation. The literature has argued that the more asymmetric the river geography the harder it is to achieve cooperation (LeMarquand 1977; Haftendorn 2000). This is notoriously most common in upstream-downstream situations. In opposition, the more symmetric the river geography (i.e. the more retaliation is internalized to the river system), the less feasible conflict becomes. In other words, the more the river straddles the international boundary the more conducive such a typology may be for inter-state coordination over the river (Toset et. al 2000).

4. Data and Variables

Based on the literature reviewed earlier, we divide our data construction efforts into two parts. We focus first on data and variables that represent water supply variability in a basin. At a second stage we discuss the data and variables that represent the international relations, economic, political and institutional situation in the basin countries, and the basin geography.

Data on climate and water variability

Basin maps

A list of 224 bilateral basins is adopted from Dinar, S. (2008) (See Map 1). The Transboundary Freshwater Dispute Database (TFDD) provided geo-referenced basins for almost all the international river basins (http://www.transboundarywaters.orst.edu/database/). Since some of the bilateral basins are sub-basins of TFDD basins, or are not included in the TFDD, it was necessary to delineate the catchments for the unit of analysis—the treaty basin. When both datasets matched, we selected the TFDD basin delineation. Otherwise the remaining basins were identified using ancillary data sources (See Appendix 3). For these remaining basins, hydrologically conditioned elevation datasets (HydroSHEDS) are used to determine the flow paths and watershed boundaries.[ii] Ancillary data sources provide location information to identify the mouth of the given river. With this geo-referenced point and HydroSHEDS data, we used Environmental Systems Research Institute ArcGIS software to delineate the catchment via a two-step process: first, adjusting the mouth location to the nearest center point of the 30 arc-second flow accumulation grid in HydroSHEDS and, second, employing the watershed function in

ArcGIS to delineate the catchment. For example, Map 2 shows the basin shared by Turkey and Iran. In a few cases, the publicly available data on river mouth locations were insufficient and experts from the region were consulted to verify the locations (e.g., AL-Jabbari, 2009).

Runoff data by basin and country-basin

The Global Runoff Data Center (GRDC) provided flow data for stations within international river basins (http://www.bafg.de/GRDC/EN/Home/homepage__node.html). The distribution of the GRDC data availability is not uniform across the world. Also, the temporal distribution varies widely. With additional data requirements such as 12 monthly observations per year and at least 5 years of observations, we ended up with 98 basin observations only (compared with the 224 basins in our dataset). Therefore, we could not use the GRDC data.

We turned to another alternative. Monthly runoff data over a thirty year period (1961-1990) was taken from a stand-alone hydrologic model CLIRUN-II (Strzepek et al., 2008) that is designed for application in water resource projects and generates global output at a 0.5 x 0.5 degree grid scale. The basin runoff is the sum of the area-weighted runoff from the grids within the basin. The flows are calculated for three values per basin: for the entire basin and for the area of the basin in each riparian country (country-basin). For the country-basin level, international boundaries from the World Bank (2009) are used and intersected with the river basin boundaries. Then, similar to the country-basin level runoff, the basin runoff is the sum of the area-weighted runoff from the grids with the treaty basin Runoff values expressed in units of m^3/s. The annual Coefficient of Variation (CV) is calculated to measure runoff variance.

To verify the values produced by the global stand-alone hydrologic model CLIRUN-II (Strzepek et al., 2008), we calculated their correlation with the runoff data that is recorded by the Global Runoff Data Center for various (98) world rivers and runoff estimates provided by the GRDC-UNH Composite Runoff Fields V1.0 (Fekete et al., 2000). We found that the correlation between the GRDC-based flow data and the CLIRUN-II based data for the same 98 basins was R^2=0.846. This correlation gives us confidence in the data we calculated from the stand alone hydrological model so that we can use the remaining 126 observations for which actual flow data is not available in the GRDC dataset. Then, comparing the two model results using the Pearson method, the correlation statistic between the mean annual runoff of CLIRUN-II and UNH-

GRDC Composite Runoff Fields V1.0 is 0.97 with 222 pair-wise complete observations out of 224 total. We tested also for the possibility of a basin area effect where small basins may have good correlation due to more concentration of gauging stations. We found the basin area variable is not significant. This result gives us confidence that the CLIRUN-II model results are reasonable and have the added advantage of a time-series for this analysis.

Precipitation data

Precipitation data are available from Mitchell and Jones (2005) from the Climate Research Unit (CRU) and downloaded from the CGIAR website.[iii] These global data are a time-series from 1900-2000 at 0.5 grid. Mean precipitation is summarized by basin and by country-basin separately. The same procedure, as in the case of runoff, was used to calculate precipitation of basin and country-basin annual means and Coefficient of Variation (CV). The aggregated data are provided by running the algorithm for both the basin-country-polygons and the basin polygons. Precipitation is expressed in units of millimeters per year.

Water variability variables

We were able to construct several sets of water variability variables for precipitation and for runoff. While our data allows calculation of precipitation at country-basin and at basin levels, the runoff variables could be calculated only at basin level. Technically, it is possible given the caveat that the country-basin will further split up the total area and will likely lessen the number of model observation(s) per basin-country. This reduction in observations gives room to a larger potential error and a lesser likelihood of actual gauge station observations in the basin for the model. We constructed the following variables: Mean precipitation for country1/basinj (*MeanPb1*); Mean precipitation for country2/basinj (*MeanPb2*); Mean precipitation for basinj (*MeanPb*); Coefficient of Variation of precipitation country1/basinj (*CVPb1*); Coefficient of Variation of precipitation country2/basinj (*CVPb2*); Coefficient of Variation of precipitation basinj (*CVPb*); Mean runoff for basinj (*MeanRb*); Coefficient of Variation of runoff basinj (*CVRb*).

Data on economic, political and international relations

We use several sources to construct our economic, political, geography, and international relations variables. We will explain the processes we used in order to calculate each of these variables in the context of a basin/country or in the context of a basin (containing the area of the basin for the two riparians).

Democracy and governance

We employ 4 variables that measure level of democracy and governance in a country, using data from Neumayer (2002a:145-146). The variables include a combined index of political rights and civil liberties, a combined index of democracy and autocracy, Vanhanen's index of democracy, and a combined governance indicator, based on seven other indicators that measure governance quality. Three of the democracy/governance variables also have a dummy version. The variables are (1) a combined index of political rights and civil liberties (*Freedind*); a combined index of democracy and autocracy (*Politind*); Vanhanen's index of democracy (*Autodemo*); and a combined governance indicator, based on seven other indicators that measure governance quality (*Voiceind*). Three of these variables also have a dummy (0-1) version (*Freeddum*, *Politdum*, *Voicedum*). The exact definition of the democracy variables can be found in Neumayer (2002a).

Variables in the democracy and governance categories are expressed as indexes or as dummies and are calculated for each country in the basin. We expect that some of the democracy variables and the governance variables are correlated somehow due to the nature of the specification of several of the democracy variable (political rights and civil liberties; governance quality). Therefore, we will not use democracy and governance as independent variables in the same equation.

Trade and diplomatic ties

These variables pertain to two riparian states in each basin and thus they are calculated as basin-level variables.

Trade

We obtained two separate trade datasets. The first is the Direction of Trade Statistics (DOTS) Database IMFDOT that includes trade information for 184 countries for the period 1950-2004, in current US$. The second dataset is the United Nations Statistics Department (UNSD) dataset COMTRADE that includes information for 207 countries for the period 1962-2004 in current US$. Sources of data feeding into the IMFDOT and into the COMTRADE datasets are different and as such, differences in annual trade values can be expected. Such differences have been observed (IMF, 1999: Table 2), although differences do not exceed 10%. We constructed separate trade variables based on both the IMF and UN datasets. We converted the trade values in these two datasets into constant 1999 US$ (for IMFDOT) and 2002 US$ (for COMTRADE). We then use annual country-level GDP data from the GGDC&CB (2005) dataset, which is expressed in 1999 (for IMFDOT) and 2002 (for COMTRADE) US$ to construct our trade variables, using 2000 as the base year. Missing trade values in particular years were ignored because our trade variables are calculated as long term averages.

The following definitions apply for the two trade variables: Let *i*=1 and *i*=2 be two riparian states sharing a river. Let IMP_{12t} be import of 1 from 2 in year *t*, [= EXP_{21t}]; let EXP_{12t} be export of 1 to 2 in year *t*, [= IMP_{21t}]; let IMP_{1wt} be import of 1 from w in year *t*; let IMP_{2wt} be import of 2 from *w* in year *t*; let EXP_{1wt} be export of 1 to *w* in year *t*; let EXP_{2wt} be export of 2 to *w* in year *t*; let GDP_{1t} be gross domestic product of country 1 in year *t*; and let GDP_{2t} be gross domestic product of country 2 in year *t*; and *w* be rest of the world (not including 1 and 2).

We first constructed two annual trade variables for each trade dataset. The first variable (TRD1) expresses total trade between 1 and 2 as a fraction of the countries' GDP, expressing the economic importance of trade to the riparians (Sigman 2004). The second variable (TRD2) measures trade between 1 and 2 as a fraction of their trade with the rest of the world, expressing their dependence on each other (Reuveny and Kang 1996). The two trade variables that we apply to the two trade data sets are presented in equations (1) and (2).

$$TRD1^{12} = \frac{\sum_{t=1}^{T} \left(IMP_{12t} + EXP_{12t} \right)}{\sum_{t=1}^{T} \left(GDP_{1t} + GDP_{2t} \right)} \quad (1)$$

$$TRD2^{12} = \frac{\sum_{t=1}^{T} \left(IMP_{12t} + EXP_{12t} \right)}{\sum_{t=1}^{T} \left(IMP_{1wt} + IMP_{2wt} + EXP_{1wt} + EXP_{2wt} \right)} \quad (2)$$

where, $IMP_{12t} + EXP_{12t}$ is the total annual volume of trade between every two countries 1 and 2. Both *TRD*1 and *TRD*2 are fractions, with $0 \le TRD1, TRD2 < 1$. We will refer to *TRD*1 as *Trade importance* and to *TRD*2 as *Trade dependency*. We found that *TRD*1(IMF) and *TRD*1(UN) are highly correlated (R^2=1.000) and *TRD*2(IMF) and *TRD*2(UN) are also highly correlated (R^2=0.999). Therefore, we can use one of the datasets only. Since the IMF dataset includes more basins than the UN dataset, for the purpose of this paper only the IMF dataset is used. Since TRD1(IMF) and TRD2(IMF) are highly correlated (R^2=0.599) we selected *TRD*1UN) - *Trade importance* to be the variable we use in our regressions.

Since our unit of observation is the river, we construct the trade variable for the entire dyad. As was indicated in our analytical framework, one riparian may be more interested in signing a treaty than the other. However, the outcome (as we measure it) doesn't reveal which riparian initiated the water treaty and, thus, our trade variables measure the dyadic trade volume rather than that of each riparian state.

Diplomatic Relations

We use the Correlates of War (COW) dataset (Diplomatic Exchange (v2006.1)) for the construction of the Diplomatic relations variable. Data on diplomatic relations is available for the period 1817-2005. We capture whether either riparian had representation in the other country in a given year. In this case we assigned a value of 1 to this year. Diplomatic relations is then calculated by dividing the number of years for which any representation was recorded by the total number of years for which data is available. The resulting variable, *Diplomatic relations*, is then bounded between [0, 1].

Power asymmetries

To reflect the economic and welfare asymmetry discussed above, we use annual country-level GDP data (state level data) from the GGDC&CB (2005) dataset, and Population Action International (2004) data to calculate GDP and GDP per capita for each of the basin riparians.[iv] The ratio between the values of the riparians is the basis for the power asymmetry in the basin. The former is a measure of overall power (*Economic power*) while the latter is a measure of wealth (*Welfare power*). The two variables were constructed by dividing the value of the wealthier, or the more economically powerful riparian by the value of the less powerful riparian. Therefore, the value is always greater or equal to 1; the higher the value, the greater the power asymmetry. In our analysis we use only the variable *Economic power* per the justification provided in the theory section.

Geography

We use the 14 geographical configurations identified in Dinar S., (2008). These configurations were re-categorized into three groups, capturing the rivers that fall under the 'through-border' geography—or the most asymmetric of the river geographies—and the rivers that fall under the 'border-creator' geography—or the most symmetric of the river geographies. The remaining rivers that fall under the other configurations were included under 'other' geography, whereby this category served as the benchmark. The reasons for this regrouping are as follows: (1) the distorted distribution of the 14 categories doesn't allow the estimated regression model to be fully ranked, and (2) we are mostly interested in the impact of the two extreme geographies and their ability to explain interactions between riparian states. In fact, all the other geographies have some combination of spatial asymmetry and symmetry so ranking them would be quite impossible.

Treaty data

The treaty dataset is retrieved from several depositories and includes 226 country dyad observations.[v] Eighty-six of the corresponding rivers are not governed by treaties while 140 are, providing a diverse pool of observations to examine the hypotheses. Three hundred and eleven treaties were identified and analyzed for their content. Of these, 40 provide only periodical reaffirmation of previous treaties and do not introduce new agreements. These treaties were removed from the analysis, leaving the dataset with 271 treaties.

Treaty cooperation variables are described in our analysis as: (1) *Treaty/no-treaty*, a dichotomous variable indicating whether or not there is (are) an existing treaty (treaties)—1, or not—0, addressing any issue or several issues; and (2) *Number of treaties* signed between the river riparians (an integer ranging between 0-N that measures the number of treaties on that river).

5. Empirical Framework

The underlying empirical assumption in our analytical framework is that water variability is embedded in the basin history and may increase in the future. Past water variability, as well as concerns regarding future variability of water, affect regional relationships. For example, although some disasters caused by floods or droughts[vi] may encourage states to engage in joint mitigation efforts, we claim that it is the long-term variability that leads to enduring cooperation, codified in an agreement, between river riparians.

Based on the theory developed above, long-term cooperation among riparian states can be expressed by the following relationship

$$C = f(V; \underline{X}). \qquad (3)$$

That is, cooperation, measured through treaty relations, is a function of a vector of water supply variability (V) and of other variables ($\underline{X}$). The vector $\underline{X}$ includes democracy and governance variables, the states' overall relations (including diplomatic ties, and trade), variables measuring power asymmetry, and physical geographical setting. In the next section we provide several alternative empirical specifications for level of cooperation and for water supply variability.

Applying the framework

We analyze bilateral river basins. The unit of observation in our analytical framework is the river (Treaties are signed sometimes for certain tributaries rather for the entire basin). Cooperation between the two riparian states takes place if a treaty (or treaties) exist(s). Some of the earlier treaties in our database may no longer be in force for a variety of reasons. However, because our approach considers water variability as a long-term phenomenon and since we argue that agreements are a response to such variability we are interested in all treaty observations throughout time. We assume that while water-related issues among the riparians are interrelated and their resolution may affect each other, all are basically driven by water variability.

Measuring treaty cooperation

Two proposed expressions for *C* will be based on a cooperation relationship explaining treaty formation. Our first cooperation expression, *P*(*C*) in (4), assesses the likelihood of a treaty on any of the issues in the basin, regardless of the issue, the riparian state that faces water variability, or the period the treaty was signed.

$$P(C) = \begin{cases} 1 \; if \; at\,least\,one\,treaty\,exists\,on\,any\,issue \\ 0 \; if \; no\,treaty\,exist \end{cases} \qquad (4)$$

A second cooperation expression, *N*(*C*) in (5), is a simple arithmetic count of the number of treaties signed between the two riparian states on any issue or issues over the years. We acknowledge that cooperation may have aspects other than the nominal count of treaties existence or number of treaties. The reader is referred to the justification of using number of treaties to Dinar S. (2009).

$$N(C) = \sum_t T_t \;, \; for\, t = 1,...,T \qquad (5)$$

where T_t is the number of treaties in year t. We apply the model in (5) to the set that includes all rivers without and with treaties (0, 1, 2, …, N).

Empirical specifications, functional forms and estimation issues

The empirical specifications of the various expressions to be estimated are as follows:

Treaty/no-treaty $=f_1(.)$

Number of treaties $=f_2(.)$

The expression (.) includes a subset of the following independent variables: *CV Basin Precipitation, CV Basin Precipitation Squared*, (or *CV Basin Runoff, CV Basin Runoff Squared*), *State democracy and governance variables*, *Through-border dummy*, *Border-creator dummy* *(with all other geographies lumped together and serving as the benchmark)*, *Trade importance*, *Diplomatic relations*, *Economic power*.[vii]

The rationale for the various regressions and estimation procedures are as follows. In cases where the dependent variable is a dichotomous choice (1/0), we employ a maximum-likelihood logit model. The function guarantees probabilities in the [0,1] range. The logit form also gives a plausible shape for the marginal effects. That is, for a continuous variable X_k, at relatively high values, a marginal change will create a relatively smaller change in the probability of success (Y=1). In some cases, we also rely on a generalized linear model (GLM) procedure, which fits models, using Newton-Raphson (maximum likelihood) optimization. The GLM procedure is preferred over a conventional Ordinary Least Squares (OLS) approach when the dependent variable of interest may have a non-continuous distribution (such as ranking), and thus, the predicted values should also follow the respective distribution. Any other predicted values are not logically possible, as the effect of the predictors on the dependent variable may not be linear. The Generalized Linear Model is used to predict responses both for dependent variables with discrete distributions and for dependent variables which are nonlinearly related to the predictors. We also use a POISSON procedure in the case of the full data set to capture the non-continuous distribution of the dependent variable. The results are presented with indication of the data sets to which they refer.

To sum, our general basin-level treaty cooperation model takes the form:

$$\begin{aligned}&Water\,Treaty\,Cooperation = h(Water\,\mathrm{var}iability, Governance,\ Democracy, Gegraphy,\\&Trade, Power\,asymmetries, Diplomatic\mathrm{Relations}) + \varepsilon\end{aligned} \quad (6)$$

where ε is the error term and each variable is represented by the various measurements discussed above.

We cannot avoid addressing possible endogeneity related to modeling the relationship between trade and cooperation (Timpone, 2003). One concern is that both trade and cooperation, among the river basin riparians, might be endogenously determined in an interdependent relationship and thus, if specified in a single equation, may lead to a biased estimation. By considering trade as a long term activity among the riparians, our theory suggests that trade is determined outside of the model and is uncorrelated with the error term of the equation. Therefore, we can use trade as an independent variable in our single model estimates.

6. Results

We applied the analytical framework in the case of two climatic phenomena, namely basin variability of precipitation and basin variability of runoff. Descriptive statistics of the variables discussed and used in the paper are presented in Appendix 2.

We report separately the results for the basin precipitation variability and for the basin runoff variability. One important caveat we should address upfront is that our analysis at this stage doesn't account for water regulation in the rivers in our sample. While the IPCC (2001:Section 4.3.6.1) suggests that "…Runoff tends to increase where precipitation has increased and decrease where it has fallen over the past few years," it is important to note that dams may skew the runoff pattern. However, we found an empirically positive correlation (R^2=0.280) between mean basin precipitation and mean basin runoff in the 215 basins we could compare; and a higher positive correlation between the coefficient of variation of basin precipitation and runoff (R^2=0.729). Another interesting finding is the high correlation (R^2=0.927) between the mean country-basin precipitation values (*MeanPb1* and *MeanPb2*). The country-basin precipitation variation values (*CVPb1 and CVPb2*) were also found to be highly correlated (R^2=0.860) among the two riparians. Therefore, we will use only the basin level variable *CVPb*. This high correlation suggests that even in very large river basins in our sample, the climate characteristics are similar across the basin territories of the two riparians. Another explanation is that the model data was created from limited meteorological / runoff observations in certain geographic areas (e.g. Africa) and does not have high variance.

<u>Basin precipitation and runoff estimates</u>

We first present results of an analysis that estimated whether or not the basin precipitation variability itself and basin runoff itself can explain cooperation. Table 1 contains 3 equations. Equation (1) includes the basin precipitation variation while equations (2) and (3) include the basin runoff variation. The results indicate that basin precipitation variability (*CVPb*) and basin runoff variability (*CVRb*) explain the variance in the level of treaty cooperation across the analyzed basins, with a fitness of fit tests that are significant at a 5 percent level and better. The results confirm as well the inverted U-shape of the relationship between water variability and treaty cooperation. The finding are encouraging, but, taking the logit Pseudo R^2 of 0.044 as an indication, suggests that precipitation and runoff variability alone cannot fully explain cooperation. Using the same argument (while in the case of the GLM estimates ((1) and (3)), the Maddala R^2 is 0.284 and 0.295 respectively) we will improve the overall explanation of the GLM estimates by adding several control variables. Tables 2 and 3 introduce control variables that improve the level of explanation while keeping the significance of the results intact.[viii]

Table 2 presents the results of the Logistic runs, estimating the likelihood of forming a treaty. Equations (1)-(3) pertain to the precipitation variability where as equations (4)-(6) pertain to the runoff variability. The estimates of the precipitation variables suggest that it affects the likelihood of forming a treaty in a U-shaped pattern. The coefficients of the basin precipitation variables were found significant at a 10 percent level while the coefficients of the basin runoff variables were found significant at 5 percent to 10 percent in 2 equations and not significant in equation (6). Moving to the democracy and governance variables the Freedom variables yielded the best results in terms of significance level, across the two climate variables—precipitation and runoff. The other variables used, Voice and Polity of each of the riparian states provide consistent signs, but not always significant coefficients. The two dummy geography variables were not significant in this table. The trade variables are highly significant across all 6 equations and with the expected sign, suggesting that as in the case of the climate variables (precipitation and runoff), trade has an inverted U-shape effect on treaty cooperation. Diplomatic relations have positive and significant coefficients in all but one equation, suggesting that higher levels of the diplomatic engagement between the countries lead to increased likelihood for treaty cooperation. The Economic power variable has negative and significant coefficients, suggesting that power asymmetry in the basin would work against treaty cooperation. All 6 regressions yield stable estimates with Log Pseudo Likelihood that ranges between -58.89 and -60.45. The Wald $\chi 2$ values are significant at a level of 1 percent and better. The Pseudo R2 values are around 0.25 and much improved compared to Table 1.

Table 3 presents the results of the GLM and POISSON regressions, where the treaty cooperation is estimated using the number of treaties (including no treaties) as the dependent variable. A total of 8 equations are presented. Equations (1)-(4) use precipitation and equations (5)-(8) use runoff as the climate variables. The climate coefficients perform as expected in terms of sign and significance level, but the estimated coefficients in the runoff equations are more significant than those in the precipitation equation. The polity variables (both the Polity Dummy and the Polity Index) perform also as expected in terms of sign and significance level. They are also stable across the eight estimated equations. The Freedom Index variable did not perform well in the estimates in this table. The trade variables have the expected sign and are significant in all estimates. The Diplomatic Relations variable has the expected signs in all eight equations. However, it is significant in all regressions with precipitation ((1)-(4)), and only in two ((6), (8)) of the four equations with runoff. The Economic Power coefficient is both significant and has the expected sign in all 8 equations. In terms of overall equation fit, the GLM estimates ((1), (2), (5), (6)) have a Maddala R^2 in the range of 0.32-0.37. And the POISON estimates ((3), (4), (7), (8)) have a Pseudo R^2 in the range of 0.13-0.19, with Wald $\chi2$ values suggesting a significance at 1 percent and higher.

Overall, basin precipitation variability and basin runoff are important variables that affect treaty cooperation, both the likelihood for forming treaties, and the number of treaties signed. As expected, in all regressions both precipitation and runoff have an inverted U-shape relationship on treaty cooperation.

The various democracy/governance variables (both in index and dummy forms) indicate the positive role democracy plays in encouraging transboundary cooperation between states. The dummy forms performed better than the index from definitions and were more significant.

Geography, an important variable in the study of international water, did not provide significant results in any of the estimates. This is against expectations, although several previous studies reviewed earlier suggest similar results. A possible explanation for this performance of the geography variable is that the runoff variability already captures the geography embedded in the river basin, and that precipitation distribution between the two riparians is independent of the geography of the river. The high correlation that was found between the precipitation falling on the basin area in country 1 and that in country 2, irrespective of the geography of the river could support the insignificance of the Geography coefficients.

Trade is the most robust variable in the analysis and was significant with the expected signs in all regressions. As noted, trade has a hill shaped impact on cooperation. There are several explanations for the hill-shaped behavior of the trade variavble. First, trade among the basin riparians may not be as effective at various levels. This supports findings by some studies (e.g. de Vries 1990 and Barbieri 2002), that find that trade can lead to conflict as well given the high interdependence it fosters. And second, riparian states may explore other means and other domains to extrapolate their economic activities beyond the basin such as through trade relations with other states in basins that face lower water supply variability..

The Diplomatic relations variable behaves as expected, suggesting a positive and highly significant relationship with treaty cooperation in all regressions. The variable measuring economic power asymmetries in the basin is also negative and highly significant in all regressions. Power asymmetries impede cooperation no matter if the economically strong state is upstream or downstream. Interestingly this finding negates other statistical studies. Tir and Ackerman (2009) find that power asymmetries are conducive to treaty formation while Espey and Towfique (2004) find that power asymmetries are insignificant for treaty formation. The policy implications of these findings are presented in the concluding section of the paper.

Marginal impacts

Calculations of marginal impacts of the main variables on treaty cooperation are presented in Table 4. We present results for regression estimates from Table 3 only. Values in panels (1)-(4) are for estimates with precipitation and values in panels (5)-(8) are for estimates with runoff.

The interpretation of the coefficients is as follows: An increase of 1 millimeter per year in long-term annual precipitation will lead to an increase of between 1-2 treaties. An increase in the long-term runoff of 1 m^3/s will lead to an increase of between 3-5 treaties. An increase in the trade importance, measured as the ratio between trade and GDP of the basin states, in 1 percent, will lead to an increase of between 1-14 treaties. An increase in the status of diplomatic ties between the riparian states will lead to an increase of between 1-3 treaties. And an increase of 1 percent in the ratio of economic power between the basin states will lead to a very small decrease in the number of treaties signed.

7. Conclusions, Policy Implications, and Future Research

Views in the extant literature, including the IPCC, raise concerns that "One major implication of climate change for agreements between competing users (within a region or upstream versus downstream) is that allocating rights in absolute terms may lead to further disputes in years to come when the total absolute amount of water available may be different." (IPCC, 2001: Section 4.7.3). Indeed, having an appropriate treaty arrangement that does not confront climate impacts such as increased variability may lead to increased likelihood of disputes. However, what our paper argues is that climate change affects not only the variability of precipitation and runoff, but also the interest of riparian states in international rivers to look for solutions to these phenomena by altering existing treaties and by signing new treaties among the basin riparian states.

Using a set of variables traditionally used in economic and international relations literature on international cooperation, we are also able to make some prescriptive suggestions as to how to increase cooperation in times of climate change: strengthen democracy and governance in the basin states and develop basin integration activities such as trade, stable diplomatic relations, and economic development in order to reduce economic power asymmetry and to increase basin harmonization. While there is not much new in this message, it comes with a quantitative demonstration and with the connotation of climate change impact on cooperation.

While our work provides a first attempt at looking into the relationship between climate change and treaty cooperation, it is certainly far from being complete. Additional analyses could benefit from inclusion of the treaty institutions, and especially those related to past water allocation regimes, as a possible response to increased water variability. We also plan on extrapolating the functions by introducing predicted values for precipitation and runoff into the time horizon for which Global Circulation Models (GCMs) calculate future precipitation and temperature as affected by future climate change. And finally, some of our present variables are still at the state level rather than at the basin level. The interaction between local, basin-level, and state-level variables (e.g., GDP, population) would add an important dimension to the analysis (Milner 1997).

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[2] The World Bank does not express any legal ramifications from the borders.

Table 1: Water supply variability impact on treaty likelihood and cooperation

Dataset Specifications	**All Rivers**		
Dependent Variable	*Number of treaties*	*Treaty/No Treaty*	*Number of treaties*
Estimation Procedure	GLM (1)	Logit (2)	GLM (3)
CV Basin Precipitation	0.398* (1.67)		
CV Basin Precipitation squared	-0.216* (-1.74)		
CV Basin Runoff		6.781*** (3.17)	3.240*** (2.87)
CV Basin Runoff squared		-4.238*** (-2.96)	-1.538*** (-3.11)
Constant	1.110** (2.05)	-1.017** (-2.11)	0.455* (1.74)
No. of Observations	215	220	220
Log Pseudo Likelihood	-409.40		-412.37
Log Likelihood		-140.28	
Pseudo R^2		0.044	
Wald χ^2		12.95***	
Maddala R^2	0.284		0.295

In parentheses are t-values. *** (p<0.01); ** (p<0.05); * (p<0.10).

Table 2: Likelihod of treaty formation

Dataset Specifications	**All Rivers**					
Dependent Variable	*Treaty / No Treaty*					
Estimation Procedure	Logit (1)	Logit (2)	Logit (3)	Logit (4)	Logit (5)	Logit (6)
CV Basin Precipitation	3.426* (1.87)	2.902* (1.86)	2.433* (1.79)			
CV Basin Precipitation squared	-0.879* (-1.76)	-0.630* (-1.69)	-0.471* (-1.61)			
CV Basin Runoff				7.066** (1.96)	6.577* (1.73)	5.355 (1.50)
CV Basin Runoff squared				-3.337* (-1.67)	-2.909 (-1.39)	-2.398 (-1.20)
VoiceIND1	0.621* (1.76)			0.743** (2.07)		
VoiceIND2	-0.430 (-1.10)			-5.624 (-1.34)		
FreedomIND1		-0.212** (-2.27)			-0.256*** (-2.56)	
FreedomIND2		0.259** (2.17)			0.305** (2.39)	
PolityIND1			0.113** (1.92)			0.117** (2.08)
PolityIND2			-0.106 (-1.47)			-0.124 (-1.59)
Through-border	-0.056 (-0.12)	-0.097 (-0.20)	-0.036 (-0.08)	-0.083 (-0.18)	-0.142 (-0.31)	-0.019 (-0.04)
Border-creator	-0.811 (-0.75)	-0.880 (-0.86)	-0.622 (-0.51)	-1.119 (-1.23)	-1.117 (-1.20)	-0.857 (-0.76)
Trade importance	63.940*** (3.09)	82.189*** (3.14)	55.687*** (3.68)	62.180*** (3.23)	79.377*** (3.31)	55.813*** (3.18)
Trade importance squared	-221.88*** (-3.51)	-273.76*** (-3.41)	-195.479*** (-3.68)	-215.24*** (-3.27)	-263.54*** (-3.58)	-194.33*** (-3.54)
Diplomatic relations	4.204** (2.00)	5.155*** (2.62)	4.492*** (2.51)	3.880 (1.41)	4.799** (2.11)	4.268** (2.09)
Economic power	-0.002** (-1.72)	-0.002* (-1.65)	-0.002** (-1.96)	-0.002** (-2.00)	-0.002** (-1.96)	-0.002** (-2.21)
Constant	-4.854** (-1.98)	-5.794*** (-2.35)	-4.435** (-1.88)	-4.360* (-1.64)	-5.397** (-2.28)	-4.039** (-2.07)
No. of Observations	128	128	126	131	131	129
Log Pseudo Likelihood	-60.43	-59.25	-58.89	-60.45	-59.15	-59.73
Wald χ^2	37.65***	38.02***	36.29***	38.59***	39.96***	36.77***
Pseudo R^2	0.239	0.254	0.236	0.257	0.273	0.244

In parentheses are t-values. *** ($p<0.01$); ** ($p<0.05$); * ($p<0.10$).

Table 3: Cooperation estimates applied to the full data set (Poisson and Normal distributions)

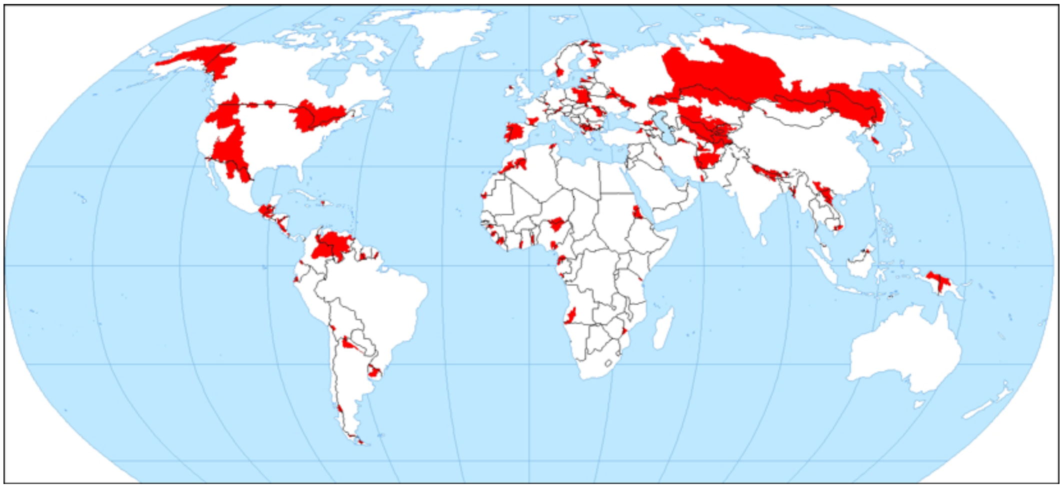
Dataset Specifications	**All rivers**							
Dependent Variable	Number of treaties							
Estimation Procedure	GLM (1)	GLM (2)	POISSON (3)	POISSON (4)	GLM (5)	GLM (6)	POISSON (7)	POISSON (8)
CV Basin Precipitation	3.984** (1.95)	3.229* (1.70)	2.307** 1.95)	1.512*** (2.65)				
CV Basin Precipitation squared	-1.454* (-1.64)	-0.932 (-1.16)	-0.797 (-1.53)	-0.324** (-2.15)				
CV Basin Runoff					6.491*** (2.69)	6.864*** (2.89)	4.662*** (3.40)	3.997*** (3.14)
CV Basin Runoff squared					-3.354** (-2.18)	-3.120** (-2.10)	-2.510*** (-2.80)	-1.667** (-1.99)
PolityLowDUM1		-1.737*** (-4.04)		-1.111*** (-3.34)		-1.792*** (-4.68)		-1.224*** (-4.27)
PolityLowDUM2		0.679* (1.71)		0.516 (1.47)		0.983** (2.08)		0.585 (1.50)
PolityMedDUM1		-1.490*** (-4.20)		-1.258*** (-4.03)		-1.698*** (-4.82)		-1.553*** (-4.43)
PolityMedDUM2		-0.108 (-0.36)		-0.350 (-1.03)		-0.393 (-0.78)		-0.489 -1.21
FreedomIND1	-0.097 (-1.40)				-0.110* (-1.78)			
FreedomIND2	-0.025 (-0.28)				-0.028 (-0.29)			
PolityIND1			0.063*** (2.85)				0.063*** (2.85)	
PolityIND2			0.006 (0.24)				0.026 (0.78)	
Through-border	-0.226 (-0.76)	-0.307 (-0.98)	-0.178 (-0.91)	-0.214 (-1.10)	-0.259 (-0.90)	-0.338 (-1.14)	-0.243 (-1.24)	-0.279 (-1.48)
Border-creator	0.456 (0.55)	0.620 (0.80)	0.263 (0.66)	0.390 (1.14)	0.224 (0.28)	0.383 (0.48)	0.064 (0.16)	0.191 (0.52)
Trade importance	20.012** (12.03)	17.605** (1.95)	.048*** (2.54)	7.151** (2.28)	16.451** (1.96)	13.923** (2.02)	5.291* (1.81)	2.666 (0.90)
Trade importance squared	-73.537*** (-2.48)	-65.510*** (-2.39)	-35.128*** (-3.02)	--32.430*** (-2.80)	-61.876*** (-2.43)	-52.505*** (-2.46)	-26.637** (-2.33)	-18.240 (-1.58)
Diplomatic relations	2.067*** (2.54)	2.481*** (3.12)	1.295* (1.83)	1.564*** (2.45)	1.308 (1.41)	1.928*** (2.40)	0.822 (0.90)	1.074* (1.62)
Economic power	-0.001*** (-3.45)	-0.001*** (-3.67)	-0.002*** (-2.38)	-0.002*** (-2.43)	-0.001*** (-3.81)	-0.016*** (-4.42)	-0.002** (-2.28)	-0.002*** (-2.38)
Constant	--1.521 (-1.13)	-1.915 (-1.38)	-2.269** (-2.29)	-1.531 (-1.55)	-0.348 -(0.36)	-1.36* (-1.65)	-1.928** (-2.17)	-1.156* (-1.81)
No. Of Observations	128	126	126	126	131	129	129	129
Log Pseudo Likelihood	-246.64	-239.05	-200.05	-194.03	-248.69	-239.04	-197.95	-189.95
Maddala R^2	0.351	0.325			0.374	0.372		
Wald χ^2			63.81***	82.22***			90.81***	147.76***
Pseudo R^2			0.138	0.164			0.161	0.195

In parentheses are t-values. *** (p<0.01); ** (p<0.05); * (p<0.10).

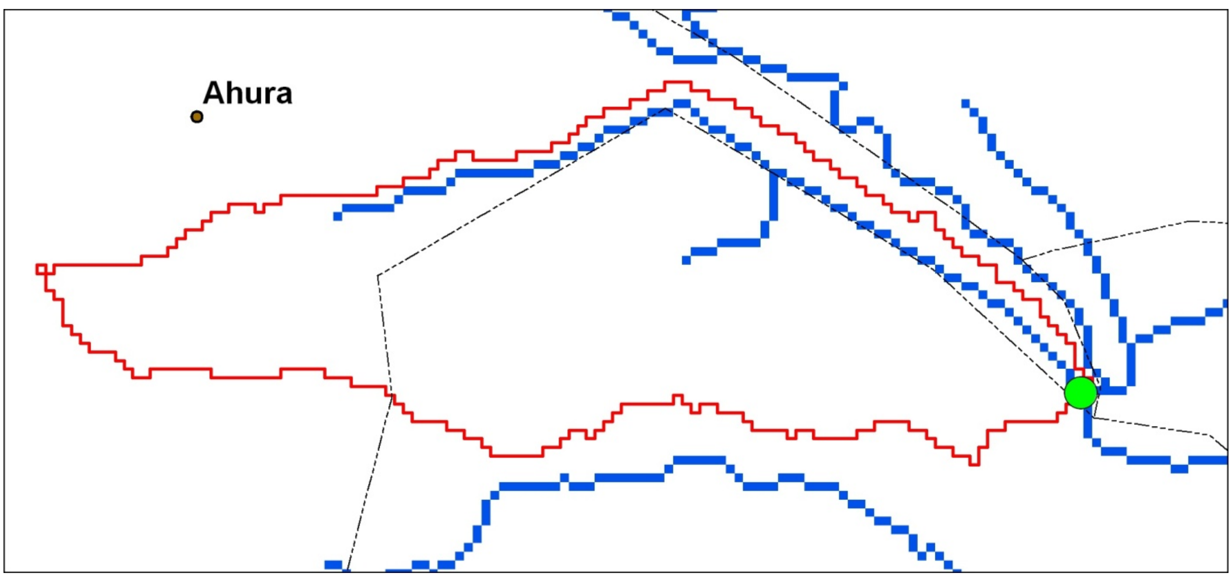
Table 4: Marginal values of main variables calculated at the sample mean (using results of estimates in Table 3)

Dataset Specifications	**All rivers**							
Dependent Variable	Number of treaties							
Estimation Procedure	GLM (1)	GLM (2)	POISSON (3)	POISSON (4)	GLM (5)	GLM (6)	POISSON (7)	POISSON (8)
CV Basin Precipitation	1.719	1.778	1.065	1.08				
CV Basin Runoff					4.260	4.789	2.993	2.887
Trade importance	14.303	12.519	5.320	4.633	11.64	9.847	3.22	1.250
Diplomatic relations	2.067	2.481	1.695	1.950	1.308	1.928	1.022	1.263
Economic power	-0.001	-0.001	-0.002	-0.003	-0.001	-0.016	-0.002	-0.003

Appendix 1: Maps



Map 1 : Distribution of bilateral basins used in our study



Map 2 : Karasu basin delineated by HydroSHEDS data: where red is the basin, blue is the accumulation flow grid > 400, green dot is the outflow point, dashed black line is the international boundary, and brown circle is a place name.

Appendix 2: Descriptive Statistics of variables included in the regression analyses

Variable	Unit	Mean	Std. Dev.	Min	Max	Obs.
Border-creator	Dummy	0.068	0.252	0	1	220
Diplomatic relations	Dummy	0.877	0.167	0	1	183
Economic power	Ratio	207.676	2032.176	1.06	25995.83	164
Number of treaties	Integer	1.25	1.61	0.00	10.00	220
Through-border	Dummy	0.45	0.498	0	1	226
Trade dependency	Percent	0.037	0.062	9.89e-05	0.243	214
Trade importance	Percent	0.038	0.089	1.49e-05	0.315	169
Treaty/no-treaty	0/1	0.61	0.488	0	1	220
Country 1 Freedom ind	Index	6.28	3.58	2	14	220
Country 2 Freedom ind	Index	6.35	3.77	2	14	220
Country 1 Polity ind	Index	5.32	5.62	-9	10	217
Country 2 Polity ind	Index	4.83	6.10	-9	10	217
Country 1 Voice ind	Index	0.267	0.939	-1.78	1.69	220
Country 2 Voice ind	Index	-0.222	1.01	-1.75	1.69	220
Basin Precipitation mean	mm/year	964.10	712.35	26.80	3110.15	215
Basin Precipitation CV	Ratio	0.778	0.340	0.264	2.23	215
Basin Runoff mean	m^3/s	1014.53	3520.36	0.389	37434.13	220
Basin Runoff CV	Ratio	0.332	0.272	0.086	2.45	220

Appendix 3: Sources to identify non-TFDD basin locations

The following table lists the sources of basins that are not included in the TFDD and were delineated for this analysis using information from the given sources accessed in 2009 and HydroSHEDS, except for Tobol, which did not have sufficient geographical coverage; so Hydro1k was used.

RIVER	Source
ALLAINE	http://en.wikipedia.org/wiki/Allaine
ARGUN	http://en.wikipedia.org/wiki/Argun_River_(Asia)
BELLI DRIM	http://www.inweb.gr/workshops/sub_basins/8_Drin.html
BERMEJO	http://www.hidricosargentina.gov.ar/estad2004/sus-ju-sa-tuc.htm
BOJANA	http://en.wikipedia.org/wiki/Bojana_River
BULGAN	http://www.welcome2mongolia.com/wp-content/uploads/2008/11/maps_physical-map-of-mongolia1.jpg
CAROL	http://www.ecolex.org/server2.php/libcat/docs/COU-143747E.pdf
CHANZA	Grande J.A. et al. "Comparative of acid drainage process types between two streams of the Cobica river in the environment of the Iberian Pyrite Belt (Huelva, Spain) and impact on the Andévalo Dam." http://www.imwa.info/docs/imwa_2005/IMWA2005_016_Grande.pdf
CHU	http://en.wikipedia.org/wiki/Chu_River; http://www.advantour.com/img/kyrgyzstan/kyrgyzstan-map-mid.jpg;
CHUT DE CHATELOT	http://www.iiasa.ac.at/Admin/PUB/Documents/IR-05-007.ps; http://en.wikipedia.org/wiki/Doubs_River;
DESNA (SMOLENSKA)	http://en.wikipedia.org/wiki/Desna_River; http://en.wikipedia.org/wiki/File:Dnepr_Basin_River_Town_German.png;
DOVERIA	Rouiller and Joris, 2000, "L'ovaille de Gondo" ; Murray, J, 1905, "Handbook for Switzerland and the Adjacent Regions of the Alps" p 190;
DUVERIJ (DOVEYRICH)	http://www.traveljournals.net/explore/iraq/map/m4384670/nahr_ad_duwayrij.html
EGER (OHRE)	http://en.wikipedia.org/wiki/Ohre
GADA/ GOULBI	http://en.wikipedia.org/wiki/Goulbi_de_Maradi_river
GANDAK	http://www.mapsofworld.com/nepal/nepal-river-map.html
GANDER	http://en.wikipedia.org/wiki/Gander_(french_river)
GANGIR	http://water.worldcitydb.com/kangir_4388238.aspx
GRANDE DE TARIJA	http://www.hidricosargentina.gov.ar/estad2004/sus-ju-sa-tuc.htm
HAL HA	http://www.welcome2mongolia.com/wp-content/uploads/2008/11/maps_physical-map-of-mongolia1.jpg
HERMANCE	http://en.wikipedia.org/wiki/Hermance_(river); herm_PD_ANIERES_DOC1_chap8.pdf;
JUDRIO	http://www.natisoneinbici.it; http://www.wein-plus.com/italy/Collio+DOC_B6141.html;
KANJAN CHAM	Ali, Mukdad, "Transboundary waterways and streams along the Iraq-Iran border lines… the reality and future"
KARASU	http://www.britannica.com/EBchecked/topic/622548/Lake-Van; Lippincott's New Gazetteer; International Boundary Study - Iran – Turkey Boundary 1963
KERULEN	http://en.wikipedia.org/wiki/Kherlen_River
KOMADOUGOU-YOBE	http://water.worldcitydb.com/
KOOTENAY	http://en.wikipedia.org/wiki/Kootenai_River
KOSI	http://en.wikipedia.org/wiki/Kosi_River
KURICHHU	http://www.brahmatwinn.uni-jena.de/brahmatwinnwiki/uploads/3/3a/3_Sherab_Tashi_Hydropower.pdf; http://www.lonelyplanet.com/shop_pickandmix/previews/bhutan-3-eastern-bhutan-preview.pdf;
LATORICA	http://en.wikipedia.org/wiki/Latorica_River
MAHAKALI (Pencheshwar Project)	http://csmrs.gov.in/ar_03.html; http://www.traveljournals.net/explore/india/map/m2929559/sarju_river.html;
MAHAKALI (SARADA)	http://www.mapsofworld.com/nepal/nepal-river-map.html;

	http://en.wikipedia.org/wiki/Sarda_River;
MAHAKALI (TANKAPUR PROJECT)	http://en.wikipedia.org/wiki/Sarda_River; http://www.uttaranchalirrigation.com/hydro/commission/tanakpur.htm;
MAIR (MERA)	http://en.wikipedia.org/wiki/Mera_River
MELEZZA	http://water.worldcitydb.com/
MILK	http://en.wikipedia.org/wiki/Milk_River_(Montana-Alberta)
MONT CENIS	http://www.gutenberg.org/files/24787/24787-h/images/map291.png
NEGRO	http://en.wikipedia.org/wiki/Río_Negro_(Uruguay)
NEW	http://en.wikipedia.org/wiki/New_River_(California)
NIAGARA	http://en.wikipedia.org/wiki/Niagara_River
OLSA	http://en.wikipedia.org/wiki/Olza_River
ONON	http://www.welcome2mongolia.com/wp-content/uploads/2008/11/maps_physical-map-of-mongolia1.jpg; wikipedia;
ORAWA	http://en.wikipedia.org/wiki/Orava_River
PETRUVKA	http://en.wikipedia.org/wiki/Petruvka_River
PRUT	http://en.wikipedia.org/wiki/Prut_River
QURAI/CURAIM	http://en.wikipedia.org/wiki/Quaraí_River
RENO DE LEI	http://en.wikipedia.org/wiki/Lago_di_Lei
ROYA	http://en.wikipedia.org/wiki/Roya_River
SAAR	http://en.wikipedia.org/wiki/Saar_River
SALZACH	http://en.wikipedia.org/wiki/Salzach
SARISU	http://water.worldcitydb.com/
SEIM (KURSKA)	http://en.wikipedia.org/wiki/Seym_River
SELENGA	http://en.wikipedia.org/wiki/Selenga
SEVERSKY DONETS	http://en.wikipedia.org/wiki/Seversky_Donets
SIRET	http://en.wikipedia.org/wiki/Siret_River
SOURIS	http://en.wikipedia.org/wiki/Souris_River
SPOL	http://www.gramene.org/db/ontology/search?id=149514; http://en.wikipedia.org/wiki/Spöl;
ST. MARY	http://www.chrs.ca/Rivers/StMarys/StMarys-F_e.htm; http://en.wikipedia.org/wiki/St._Mary_River;
TAGWAI/EL FADAMA	http://water.worldcitydb.com/
TEESTA	http://en.wikipedia.org/wiki/Tista_River; http://www.sandrp.in/rivers/Teesta_River_flowing_through_tunnels_Apr2008.jpg;
TIB (MEHMEH)	Ali, Mukdad, "Transboundary waterways and streams along the Iraq-Iran border lines… the reality and future"; Lawrence G. Potter "The Evolution of the Iran-Iraq Boundary" Chapter 4;
TIMOK	http://en.wikipedia.org/wiki/Timok_River
TOBOL	http://en.wikipedia.org/wiki/Tobol_River
TORRENTE BREGGIA	http://en.wikipedia.org/wiki/Breggia; http://en.wikipedia.org/wiki/Lake_Como;
TUNDZHA	http://en.wikipedia.org/wiki/Tundzha
USSURI	http://water.worldcitydb.com/ussuri_river_2691300.html
UZH	http://en.wikipedia.org/wiki/Uzh_River
WANGCHU	http://www.fao.org/docrep/field/003/P8793E/P8793E02.jpg; http://www.brahmatwinn.uni-jena.de/brahmatwinnwiki/uploads/3/3a/3_Sherab_Tashi_Hydropower.pdf;
WITKA/SMEDA	http://water.worldcitydb.com/
YAGUARON/JAGUARAO	http://en.wikipedia.org/wiki/Jaguarão_River

Endnotes

[i] In this paper we analyze only bilateral treaties. The analysis of multilateral treaties necessitates a different set of assumptions regarding the interactions among (N>2) riparian states. The inclusion of multilateral basins in the analysis will take place in a future study.

[ii] HydroSHEDS is a dataset in the public domain of conditioned Shuttle Radar Topography Mission (SRTM) elevation data (90m resolution) that used a series of processing steps that alter the elevation values in order to produce a surface that drains to the coast (except in cases of known internal drainages). Further steps include filtering, lowering of stream courses and adjacent pixels, and carving out barriers to streamflow. Flow accumulation and flow direction grids (30 arc seconds) were downloaded at: http://gisdata.usgs.net/Website/HydroSHEDS/viewer.php.

[iii] http://cru.csi.cgiar.org/

[iv] In a future study we plan incorporating GIS overlays to estimate the proportion of GDP in the part of a basin of the country (static variable) that uses spatially disaggregated GDP data based on sub-national data at the World Bank (for 2000).

[v] International Freshwater Treaties Database, Oregon State University; League of Nations Treaty Series; United Nations Treaty Series; United States Treaties in Force; Food and Agriculture Organization (1978; 1984); Food and Agriculture Organization (FAOLEX and WATERLEX); United Nations Economic Commission for Europe (UNECE, 2003); French Ministry of Foreign Affairs; Repertorio Cronológico de Legislación (Spain); Central Asia Regional Water, Environment, and Energy Agreements, Department of Civil Engineering at the University of Texas; International Water Law Project; Parry (1969); Rohn (1984).

[vi] Future analysis could identify the number of known floods or droughts in recent history by basin based on UNEP / WB, UNISDR report, and Dartmouth Observatory data: http://www.grid.unep.ch/activities/earlywarning/preview/ and http://www.preventionweb.net/english/hyogo/gar/report/index.php?id=1130&pid:34&pih:2 and http://www.dartmouth.edu/~floods/

[vii] On a technical note, relationships based on (4) will be estimated using Logit procedures, while relationships based on (5) will be estimated using GLM or Poisson procedures. For the reader needing more details please refer to Maddala (1983). For equations with *Treaty/no-treaty*, values of the independent variable are 0/1 and a Logit procedure was used; for *Number of treaties*, values are in the range of 0-10 and a Poisson and GLM procedures are used.

[viii] We should note that due to missing values of several variables, we end up with a set of about 128-132 observations only. In our next stage of the research we will amend the missing data.