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Implications of hydro-political dependency for international water cooperation and conflict: Insights from new data

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ABSTRACT

Hydro-political dependencies between countries are widely regarded as having important implications for international water cooperation and conflict. Quantitative ex-post empirical research on the subject so far uses very simple characterizations of international river geography to proxy for such dependencies, though. The authors developed a new geo-spatial dataset for water catchments worldwide. This dataset combines elevation models, flow accumulation approaches, hydrological data, and data on international boundaries to generate more precise and nuanced measures of hydro-political dependencies among riparian countries. The paper discusses these measurement concepts, illustrates how dependencies are distributed worldwide, and revisits three prominent quantitative studies on the issue to show how using improved data affects empirical findings. In contrast to a very popular presumption, upstream–downstream dependencies turn out to have a very small to insignificant effect on international water cooperation or conflict.

Introduction

Growing population density and economic activity combined with unsustainable water management practices are likely to result in over-appropriation and degradation of freshwater resources in many parts of the world (Alcamo, Flörke, & Marker, 2007; Vörösmarty et al., 2010). Around half of the worldwide surface water basins that are accessible to and thus crucial for humanity form part of catchments that extend beyond the boundaries of a single country (Wolf, Natharius, Danielson, Ward, & Pendler, 1999). Some of these transboundary (i.e., international) catchments experience acute water scarcity, whereas others suffer mainly from pollution. All of these problems have important implications for public health, ecosystems, and socioeconomic development.

A considerable body of scientific literature is trying to identify the factors that increase or mitigate the risk of water-related conflicts among riparian countries in international river basins. This literature also studies factors that contribute to effective international solutions to international water problems and thus settlement or avoidance of conflict (e.g., Bernauer, 2002; Bernauer & Böhmelt, 2014; Brochmann, 2012; Brochmann & Gleditsch, 2012; Brochmann & Hensel, 2009; De Stefano, Edwards, de Silva, & Wolf, 2010; Dinar & Dinar, 2003; Dinar, Blankespoor, Dinar, & Kurukulasuriya, 2010; Espey & Towfique, 2004; Furlong, Gleditsch, & Hegre, 2006; Gerlak & Grant, 2009; Gleditsch, Furlong, Hegre, Lacina, & Owen, 2006; Hensel, McLaughlin Mitchell, Sowers, & Thyne, 2008; Stinnett & Tir, 2009; Tir & Ackerman, 2009; Wolf et al., 1999; Wolf, Stahl, & Macomber, 2003; Wolf, Yoffe, & Giordano, 2003; Yoffe et al., 2004; Yoffe, Wolf, & Giordano, 2003; Zawahri & Gerlak, 2009; Zawahri & McLaughlin Mitchell, 2011; Zeitoun & Mirumachi, 2008; Zeitoun, Mirumachi, & Warner, 2010; for a recent overview, see, e.g., Bernauer & Kalbhenn, 2010).

Recent research in this area in the past decade has sought to complement the numerous qualitative case studies on individual international river catchments with large-*N* statistical analysis that compares many international river basins in an attempt to arrive at less context-specific and more generalizable results (Brochmann & Gleditsch, 2012; Brochmann & Hensel, 2009; Conca, Wu, & Mei,

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2006; Dinar et al., 2010; Espey & Towfique, 2004; Furlong et al., 2006; Gerlak & Grant, 2009; Gizelis & Wooden, 2010; Gleditsch et al., 2006; Hamner, 2009; Hensel et al., 2008; Stinnett & Tir, 2009; Tir & Ackerman, 2009; Wolf, Yoffe, et al., 2003; Zeitoun & Mirumachi, 2008; Zeitoun et al., 2010).

Most of these empirical models explaining international river basin conflict and cooperation focus on three types of outcomes. First, researchers interested in cooperative outcomes have concentrated primarily on when and why states create international river basin treaties or organizations (e.g., Dinar et al., 2010; Espey & Towfique, 2004; Stinnett & Tir, 2009; Tir & Ackerman, 2009; Zawahri & McLaughlin Mitchell, 2011). Treaties or organizations as such do not solve international water problems, however, particularly if their ambition level is low and/or they are not effectively implemented and complied with. That said, they could still serve as a rough proxy for whether riparian states are trying to deal with transboundary water problems cooperatively. They are also easy to code in numerical form for river basins worldwide. Second, researchers interested in international water conflict have mainly sought to explain the onset of militarized interstate disputes (MIDs)[4] by examining whether water scarcity or sharing an international river system, ceteris paribus, affects this (e.g., Furlong et al., 2006; Gleditsch et al., 2006). Finally, yet other researchers have coded and analyzed so-called event data. The latter capture water-related international interactions between riparian countries on a continuum ranging from extreme forms of conflict (such as armed hostilities relating to water) to highly cooperative events, such as the formation of comprehensive international institutions for cooperative river basin management[5] (e.g., Bernauer & Böhmelt, 2014; Hensel et al., 2008; Kalbhenn & Bernauer, 2013; Rothman, 2007).

International river basin geography, both in a hydrological and political sense, is considered an important explanatory factor in large-*N* studies as well as qualitative case study research on river basin conflict and cooperation. It also plays an important role in computational simulations of how climate change could affect international river basins and the amount of available renewable freshwater resources there, as well as the relations among their riparian countries (e.g., Beck & Bernauer, 2011). For instance, research that is interested in the “gravitational” or “proximity” drivers of international water conflict or cooperation requires high resolution data on international borders formed by rivers or lakes, and data on territorial or hydrological shares of countries in catchments. One argument of interest here is, for example, that any two countries with large shares in a given international river basin are more likely to experience a conflict over this river basin, or are more likely to be motivated to embark on cooperative ventures. Research interested in how differences in power affect international water-related cooperation or conflict requires accurate data on sources of power that may emanate from geophysical conditions and related locational advantages or disadvantages of countries. One popular argument here is that upstream–downstream asymmetries between countries are more conflict (and less cooperation) prone because they offer opportunities for the upstream country to pass on the negative consequences of unsustainable water use to the downstream neighbor.

The existing literature arrives at ambiguous and partly contradictory findings on the effects of river basin geography and associated hydro-political variables on international water cooperation and conflict. We submit that advancing research on this issue requires more accurate and nuanced measures of river basin geography and associated hydro-political dependencies. Primarily for the latter concept, the existing literature uses simplistic measures that are mainly based on visual inspection of maps.

We have constructed a new geo-spatial dataset that will be helpful in two ways. First, it includes information on around 450 international river basins. In contrast, the most important existing dataset, the Transboundary Freshwater Dispute Database (TFDD; Wolf et al., 1999; Wolf, Stahl, et al., 2003; Wolf, Yoffe, et al., 2003), on which almost all of the existing research is based, includes information on around 260 basins. Second, we use the new data to construct much more detailed and accurate measures of hydro-political dependencies. Specifically, we combine elevation models, flow accumulation approaches, hydrological data, and data on international boundaries to generate more precise and nuanced measures of river geography and hydro-political dependencies among riparian countries in international river basins.

To demonstrate the usefulness of the new data, we revisit three published studies that are both theoretically and methodologically very sophisticated, and that examine (among other factors) the effect of river geography on international water cooperation and/or conflict: Brochmann and Gleditsch (2012), Zawahri and McLaughlin Mitchell (2011), and Brochmann (2012). Because the datasets of these studies (like almost all others on the subject) are constructed on the basis of TFDD information on around 260 international river basins, whereas the new dataset covers around 450 basins, we cannot bring the full potential of the new data to bear. However, we show that the results of two of the three studies change significantly when we use the improved data for hydro-political dependencies. In contrast to a very popular presumption, upstream–downstream dependencies turn out to have a very small to insignificant effect on international water cooperation or conflict.

We conclude that further research should fill data gaps with respect to events data and river treaties, so that inferences on cooperation inducing (or reducing) factors can be drawn from a more comprehensive informational base. The next section describes how the new dataset and the hydro-political dependency measures were constructed. The third section shows some trends in international and domestic river basins worldwide. The fourth section uses the new data to revisit three existing studies on international river basin conflict and cooperation. We then conclude by discussing implications for further research.

River catchments and hydro-political dependencies: the new dataset

In this section, we briefly describe how we constructed the dataset and highlight the innovative parts of it. The largest part of the section is devoted to measures of hydro-political dependency because those are the most innovative part of the new dataset.

Geophysical information and political boundaries

We use the most recent and advanced geophysical information sources and information on (time-variant) political boundaries to construct a geo-spatial dataset on both domestic and international river basins worldwide. The main difference, relative to the TFDD (http://www.transboundarywaters.orst.edu), on whose geophysical variables almost all existing large-*N* empirical work on international river basin cooperation and conflict so far is based, is that we cover both domestic and international rivers, and that our data identifies many more international basins than the TFDD.

Specifically, we use three data sources for delineating water catchments: HydroSHEDS (USGS & WWF, 2006), CCM2 (Vogt et al., 2007), and HYDRO1k (USGS, 1997). We then juxtapose the most advanced GIS data on (time-variant) political boundaries on water catchments. We use a slightly updated version of CShapes (Weidmann, Kuse, & Gleditsch, 2010) to that end. CShapes provides historical maps of state boundaries and capitals in the post-World War II period (Weidmann et al., 2010). Technical details on this dataset construction effort are provided in Appendix 1.

For the time-period 1946–2012, which is covered by our dataset, we identify and characterize 4395 watersheds. 456 of these watersheds were international at least once in the time-period 1946–2012 (450 as of 2012); 3930 watersheds have been domestic throughout the entire time-period; and eight watersheds in French Guyana have a separate status because the latter is not a sovereign state.

While some studies on international water cooperation and conflict also use data for the pre-World War II period, we decided to restrict our dataset to the post-World War II period. The reason is that the political boundary identifications are much less precise for the period before 1946, and that political boundaries had a very different significance and role in many parts of the world before 1946.

The new dataset also includes information on population density and climatic conditions, which is widely used in studies of domestic and international water policy. Since the dataset also includes widely used numerical codes and names for countries and catchments, additional data will be easy to add. Details are given in Appendix 1.

Hydro-political dependency measures

As noted above, existing research relies mainly on visual inspection of maps and, on that basis, categorizations of river basin geography to characterize hydro-political dependencies. In some cases, such characterization is easy to achieve, e.g. for the Nile and the two most downstream riparians (Sudan, Egypt), or the Euphrates (Turkey, Iraq, Syria). But in many if not the majority of cases, river geographies are too complex for this approach to work well. Two examples, among many, are the Zambezi and Limpopo rivers in southern Africa (see further below). Using the newly constructed geo-spatial dataset, we constructed three types of measures that characterize hydro-political dependencies. They are based on an average elevation based concept, a flow accumulation concept, and a flow interdependence concept. Further below we add an additional concept that augments the interdependence concept with hydrological data.

First, there is the *average elevation based concept*. Of the measurement concepts we propose, this concept is the most simple. Using digital elevation data, we measure the average altitude of a country's surface area within a given catchment. The resulting measurement unit is an altitudinal value (in meters) for a given water catchment area per country. For international basins, we can thus order countries in terms of their upstream or downstream location. For instance, if countries A and B share a river basin, country A is the upstream country if its average altitude in the basin is, say, 300 m, whereas the corresponding average altitude in country B is 200 m.

This measurement concept has some limitations. In complex river geographies, where a river crosses back and forth between two countries, this measure may not properly capture differences in terms of up- or downstream location. Moreover, it does not take into account differences in countries' shares in the basin, for instance as measured by surface area of contribution to runoff. For example, in extreme cases, a very small mountainous area in a catchment that also contributes very little to total runoff will be characterized as upstream in relation to a far larger country that accounts for a much larger share of basin area and runoff contribution. In such a case, the measurement concept will not produce useful information on the hydro-political dependency between the two countries.

Second, there is the *flow accumulation concept*, which relies on flow direction and flow accumulation calculations based on digital elevation data. We re-sampled all basins shapes to a raster/grid with the same resolution as our digital elevation data and assigned the altitude to each cell. Based on these cells, we then calculated the flow accumulation for each cell and assigned values for flow accumulation where an international border intersects with the main river network. The most downstream country is the one with the largest national maximum flow accumulation value. Fig. 1 illustrates this ordering concept, while Table 1 summarizes the results of the calculations.

Third, there is the *flow interdependence concept*. The most comprehensive and sophisticated characterization of hydro-political dependency in our dataset is generated by a flow accumulation matrix that was calculated for each international river basin. Similar to the flow accumulation described above, we calculated the number of cells draining into a given country and determined the dependence of each riparian country on the other countries within a basin (Fig. 2, Tables 2a and 2b). The flow interdependence matrix then indicates the flow contribution to each of the riparian countries.

From the perspective of each country, we then determined the origin and number of cells that drain into its territory. Using the Limpopo basin as an example demonstrates the method. Upper left of Fig. 2/Table 2a: the flow into Botswana (originating from Zimbabwe and South Africa, but not Mozambique). Upper right: the flow to Zimbabwe (originating in Botswana and South Africa). Lower left: flows to South Africa, and lower right: the flows to Mozambique, the most downstream country where water from the whole river basin accumulates. Corresponding numbers can be found in Table 2b.

The flow accumulation matrix (Table 2a) resulting from the aforementioned calculations describes the flow contribution from and to each riparian country, including the internally produced contribution. It should be kept in mind that these numbers derive from geographic information (number of cells drained), and not from river runoff (water volumes). Implementing the flow

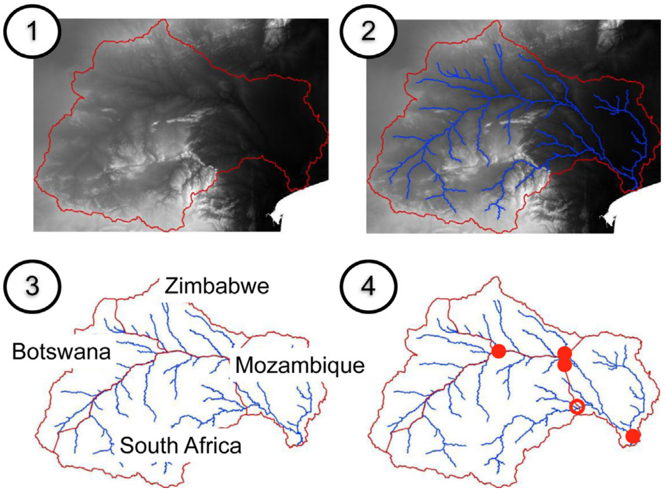

Fig. 1. Flow accumulation calculation for the Limpopo basin: (1) digital elevation model and basin delineation; (2) calculation of the river network; (3) intersection of the river network with country boundaries; (4) the highest flow accumulation value at the border crossing determines the riparian position in the catchment. The circle indicates a location where a river within the Limpopo catchment crosses the international border but does not have the highest flow accumulation value. The value of the maximum flow accumulation corresponds to the number of cells with a size of 30 arc seconds (according to the GTOPO30 dataset) draining into this point. For more details, see the dataset description in the Appendix.

Table 1
Results of the flow accumulation calculation for the Limpopo basin: The riparian position variable is normalized to 1 for the most downstream country. Mozambique is placed most downstream and Botswana most upstream. Zimbabwe and South Africa hold almost the same riparian position because they share the same main stream with almost the same accumulated flow from upstream, even though the territory of South Africa is much larger. Numbers in the table indicate the number of cells drained.

Country	Maximum flow accumulation	Riparian position
Botswana	229,687	0.45
Zimbabwe	298,364	0.58
South Africa	298,358	0.58
Mozambique	511,404	1

accumulation matrix concept based on river runoff for all catchments globally would require more detailed information on climate, soil, slopes and other factors that determine flow routing at the land surface as well as in the saturated and unsaturated zones. We return to this issue toward the end of the next section.

Some trends in river basins worldwide

Based on the new data we now describe some trends in river basins worldwide before revisiting three published studies in an effort to demonstrate the usefulness of the new data for large-*N* research.

Domestic and international river basins

As shown by Fig. 3, the number of international as well as domestic river basins increased in the decolonization period. The reason is that large land areas in Africa were not formally an integral part of the territory of any sovereign country before decolonization. This means that neither colonies nor the river basins therein in Africa appear in national statistics before decolonization. The numbers of both types of river basins were then stable in the 1970s and 1980s. At the end of the Cold War, several formerly domestic water catchments became international – hence the slight decline in the number of domestic and the increase in international water catchments.

Table 3 shows the distribution of surface areas (catchment size) of the ten largest international and domestic river basins, based on the most recent year in the dataset.

For purposes of illustration Fig. 4 shows the global distribution of surface shares (in square kilometers [km^2]) in international river basins over time; that is, the total cumulated (sum) area of all international river basins (black), and the mean area of shared river basins per country (sum divided by number of countries).

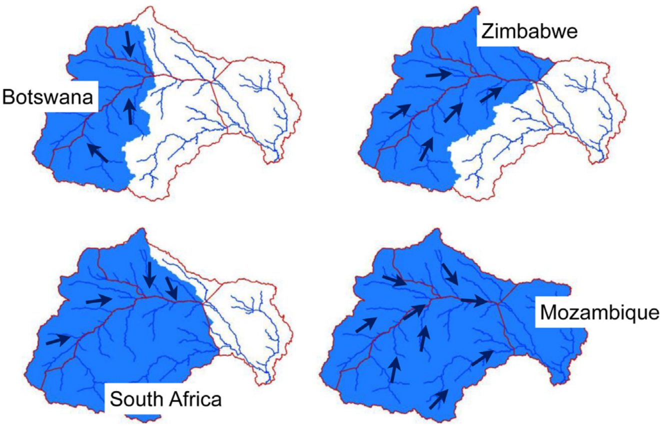

Fig. 2. Flow interdependence concept – illustration for the Limpopo basin. Arrows indicate flow directions.

Table 2a
Cell-based flow accumulation matrix from- and to the different country-basin shares for the Limpopo basin. Diagonal values indicate internally generated runoff.

		Flows from			
		Botswana	Zimbabwe	Mozambique	South Africa
Flows to	Botswana	17,914	4069	0	18,026
	Zimbabwe	17,689	13,626	39	23,623
	Mozambique	17,678	13,503	17,535	40,529
	South Africa	17,678	10,336	162	40,634

Fig. 5 offers an additional illustration of land area coverage by international river basins. This coverage increases notably during decolonization in the 1960–1970s and then increases again with the end of the Cold War. With a cutoff at 10 km^2 in terms of river basin size, there are currently more than 400 international basins.

Hydro-political dependencies

The new dataset measures hydro-political dependencies in terms of how a riparian country is positioned relative to other countries in the same international river basin or in all basins, taken together, that it shares with other countries. In addition, we introduce several measures defining to what extent a river basin as a whole is up- or downstream dominated.

We now show how such hydro-political dependencies are distributed worldwide, focusing on individual countries and their position with respect to other countries in international river basins. To that end, we use the flow interdependence concept presented above and calculate for each country how it is positioned relative to the other countries in a given river basin in the 2005–2010 period (average). If a country is part of more than one international river basin, this calculation is performed for each river basin separately.

Fig. 6 displays the average score per country. The vertical axis shows the dependency score and the horizontal axis orders all countries from highest to lowest dependency score. Low dependency scores indicate that the country is primarily an upstream country (e.g., Switzerland, in which major rivers, such as the Rhine and the Rhone originate, but into which no major river flows). High scores indicate that the country is primarily a downstream country (e.g. Romania, the most downstream country in the Danube basin).

A somewhat simpler approach is to compare the number of countries to which a given country's cells drain with the number of countries from which the country receives water. Table 4 lists 30 countries that can, on the basis of this measurement concept, be identified as being primarily water importers or water exporters respectively. Specifically, we calculated the number of countries to which country X exports water (defined as drainage cells) to (#export) and divided this number by the number of countries

Table 2b
Results of the flow accumulation calculation for the Limpopo basin: the riparian position variable is normalized to 1 for the most downstream country. Mozambique is placed most downstream and Botswana most upstream. Zimbabwe is the second viewed from upstream and South Africa the second viewed from downstream.

		Total flows (cells drained)	Riparian position
Flows to	Botswana	40,009	0.4
	Zimbabwe	54,977	0.6
	Mozambique	89,245	1
	South Africa	68,810	0.8

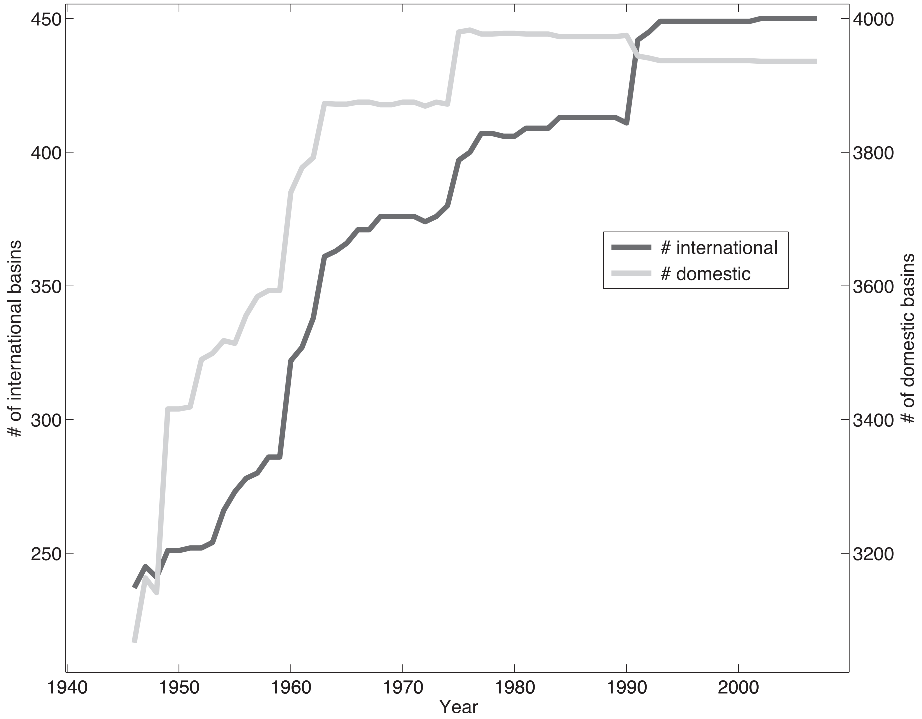

Fig. 3. Number of international and domestic river basins, 1945–2010.

from which country X imports water (#import). Table 4 lists 15 countries whose location is primarily upstream, and 15 whose location is primarily downstream.

The main limitation of the measurement concepts for hydropolitical dependency presented so far is that they focus on drainage cells (i.e. spatial units), rather than runoff. This may lead to measurement validity problems, particularly in basins with strong variation in climatic conditions across countries.

To address this potential shortcoming we created a simple representation of a global hydrological model, based on our dataset, using Precipitation (*P*), potential Evapotranspiration (ET), and the flow interdependence concept as described above. In this model, precipitation (*P*) minus potential Evapotranspiration (ET) serves as a proxy for the hydrological condition of a country or basin and indicates potential runoff.

The flow interdependence matrix concept presented in the previous section indicates the flow contribution to and from each of the riparian countries in terms of “number of cells”. Hence we know for each country and river basin the origin and number of cells that drain into and out of its territory. For the simple hydrological model we weigh this cell-based information with averaged Precipitation minus Evapotranspiration over several years (for further information on climate variables please see Appendix 1 page 4f). For purposes of illustration we do so for the year 2010. Table 5 presents this information for selected countries at both ends of the spectrum, i.e., countries that are hydrologically very independent of other countries, and countries that are very dependent.

Fig. 7 combines information from Tables 4 and 5. The horizontal axis captures the number of countries to which a given country exports drainage cells, divided by the number of countries from which the country imports drainage cells. The higher the value on that scale, the more independent the country is. The vertical axis indicates the ratio between internally generated runoff vs. imported runoff. We use a log scale because of the widespread scores. Values larger than zero on this scale indicate that more water is internally produced than imported (more independence) whereas values below zero indicate that more water is imported than internally generated (more dependence).

As shown in Fig. 7, Somalia and Egypt for example (which are very dry countries) are very dependent on other countries in terms of imported water, and also dependent on more other countries from which drainage cells are imported. Romania, in contrast, relies on many other countries for importing drainage cells, but benefits from a high level of internal runoff relative to imported runoff. Rwanda and Switzerland, to take another example, are very independent both in terms of drainage cell dependence on other countries and in terms of internal vs. imported runoff.

As noted further above the new dataset can be used not only to characterize countries, but also river basins as a whole. To examine whether a river basin is more upstream or downstream dominated we look at how dependent the most downstream country is, relative to all upstream countries. To that end we calculate the internally generated runoff, as measured by the combined flow interdependence and $P-\mathrm{ET}$ concept, of the most downstream ($\bullet_D$) basin-country intersection ($P-\mathrm{ET}_D$). Then we divide this score by the total ($\bullet_{TOT}$) generated $P-\mathrm{ET}$ of the entire basin ($P-\mathrm{ET}_{TOT}$). The larger the ratio of $(P-\mathrm{ET}_D)/(P-\mathrm{ET}_{TOT})$, the more downstream

Table 3
Surface shares of the ten largest international and domestic river basins.

International	Area [1e6 km^2]	Domestic	Area [1e6 km^2]
Amazon	6.0	Lena	2.5
Congo	3.7	Yangtze	1.9
Mississippi	3.2	Mackenzie	1.8
La Plata	3.1	Murray	0.9
Nile	3.0	Para	0.9
Ob	2.9	Lake Eyre	0.9
Yenisei	2.6	Yellow	0.8
Amur	2.2	Kolyma	0.7
Niger	2.1	Sao Francisco	0.6
Aral Sea	1.8	Colorado	0.4

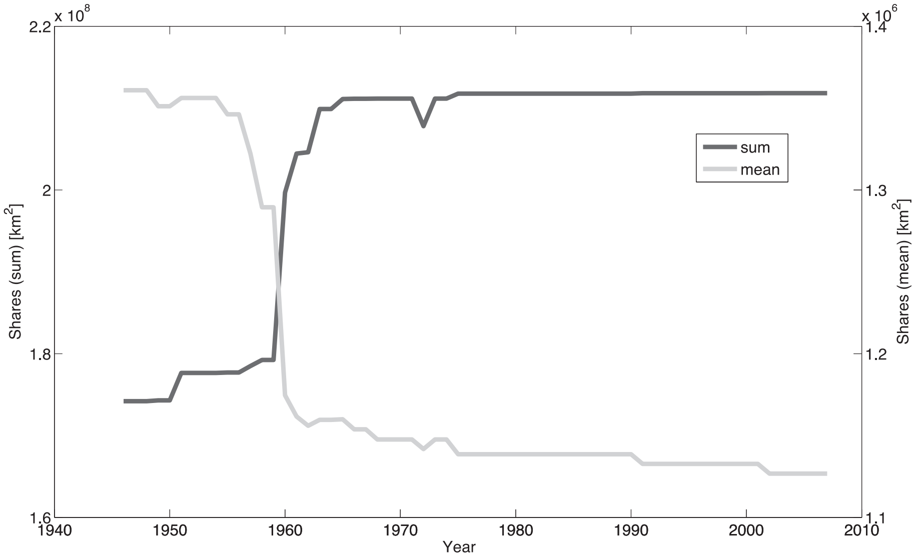

Fig. 4. Global distribution of surface shares.

dominated the respective basin is (we call this concept the "ratio concept"). The vertical axis in Fig. 8 indicates the values of $(P - \mathrm{ET_D})/(P - \mathrm{ET_{TOT}})$ in [0; 1]. The horizontal axis shows the total annual $P - \mathrm{ET}$ for a basin in m/year, measured as an average value for ten years (2001–2010).

By combining information on how dry or wet a river basin is with data on general hydro-political dependency patterns Fig. 8 offers a starting point for risk-profiling research and identification of international river management challenges. For example, basins that are drier and more upstream dominated are, arguably, likely to experience more water allocation conflicts and may thus be harder to manage. Examples include the Aral Sea, Orange, Zambezi, Lake Chad, and Shatt el Arab river basin. In contrast, basins that are wetter and more downstream dominated are likely to experience less water allocation conflicts and international management might be easier. For example, the Amazon and Orinoco basins are rather wet and neither strongly upstream- nor downstream dominated. The Mississippi, Tarim, Volga, and Yenisei are almost fully downstream dominated and three of these basins are located almost entirely in the most downstream country.

Applications

As noted above, the new data will be useful for quantitative and qualitative work of an ex-post and a prospective (ex ante) nature. In ex ante studies, for instance, it could help in computational simulations that examine how climatic changes or big changes in water demand could affect the potential for water conflict (or

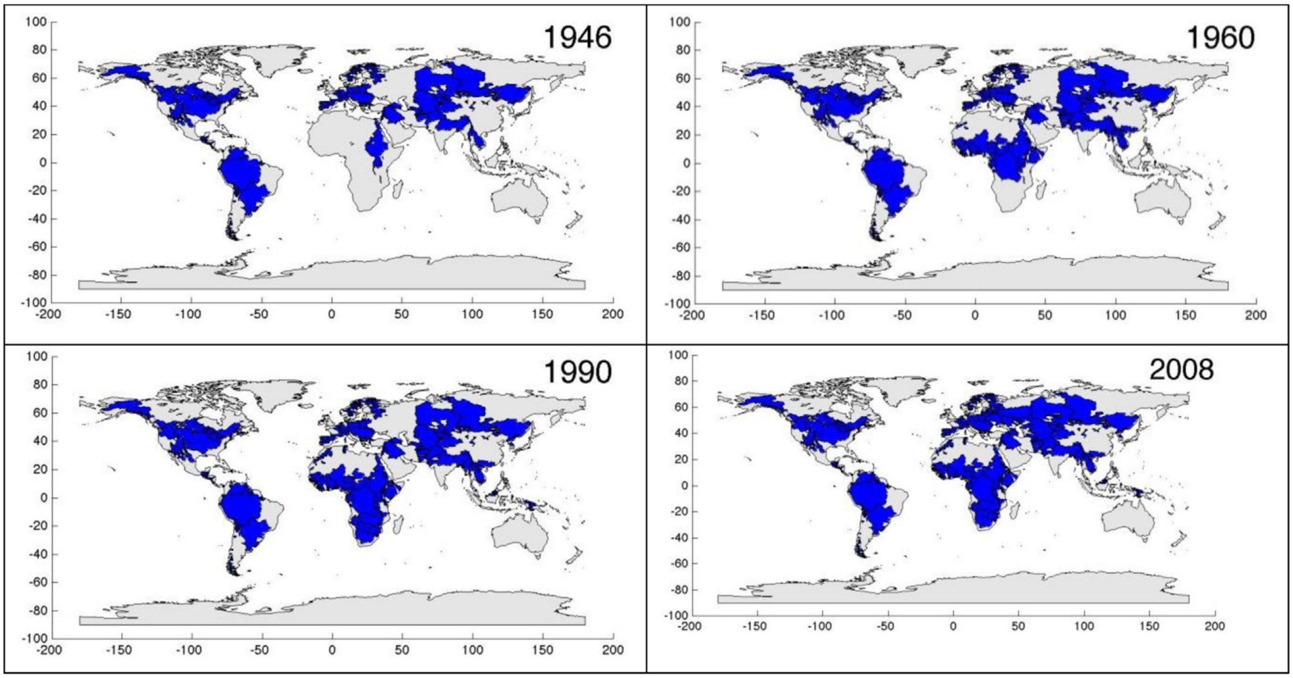

Fig. 5. Blue shading shows increasing surface share of international river basins over time.

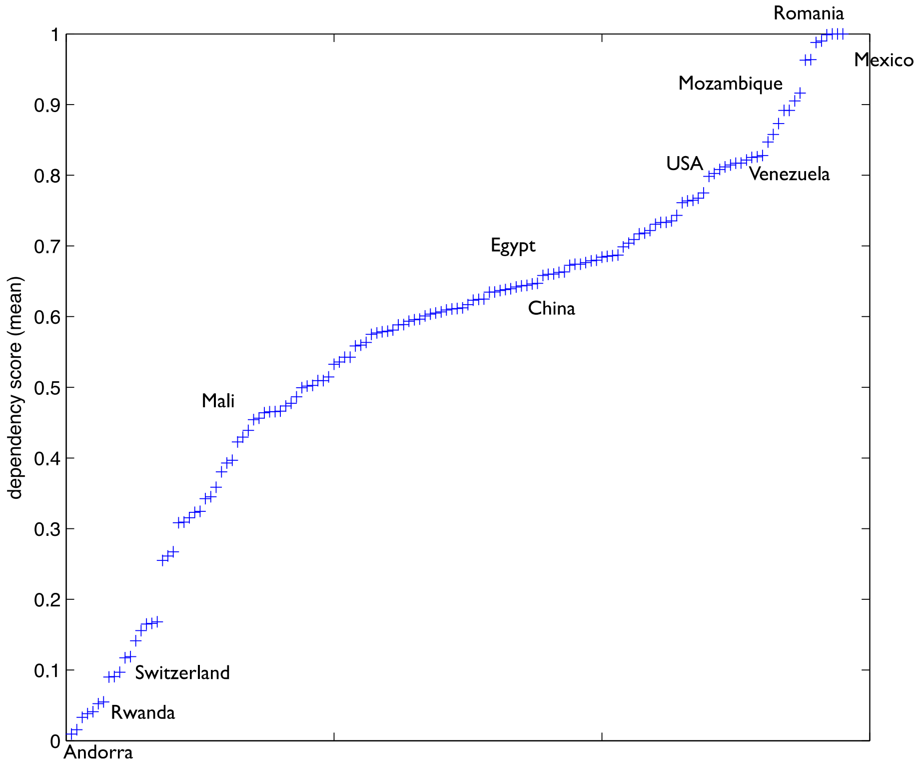

Fig. 6. Dependency score of countries: low dependency scores indicate that the country is primarily an upstream country; high scores indicate that the country is primarily a downstream country.

cooperation) among riparians of international river systems (see Beck & Bernauer, 2011). In ex-post empirical studies, it could help resolve the debate on whether and how hydro-political dependencies (most notably, upstream–downstream dependencies or asymmetries) affect cooperation and conflict.

To demonstrate the usefulness of the new data, we concentrate on ex-post empirical studies. One of the most widely shared views in this literature is that upstream–downstream asymmetries (or what we call hydro-political dependencies) affect the prospects for international water cooperation and conflict (e.g., Brochmann, 2012; Brochmann & Hensel, 2009; Dinar et al., 2010; Tir & Ackerman, 2009). However, whether such dependencies contribute to conflict, to cooperation, or to both, and if so to what extent, remains unresolved.

To help addressing this debate more accurately, we revisit three recently published studies on the issue that we regard as very well done, both in theoretical and empirical terms, and that include river geography (or hydro-political dependency) as an explanatory factor. We replace their river geography/water dependency data with our new data and examine the implications for the results. The three studies are by Brochmann and Gleditsch (2012), Zawahri and McLaughlin Mitchell (2011), and Brochmann (2012). Each of these studies focuses on one of the three types of outcome variables that dominate the relevant literature: militarized interstate disputes,

Table 4
Water exporting and importing countries, identified by the flow interdependence concept. Some of these countries might not be intuitively obvious. Egypt for instance who receives almost all its waters from the Nile (in terms of quantities) from other countries could be expected to be a total importing country. However, Egypt is actually also exporting water to Jordan and Libya through small upstream shares of river basins and therefore not appearing on this list.

(# Export/# import)	Water exporting countries	(# Export/# import)	Water importing countries
1.43	Rwanda	0.00	Azerbaijan
1.13	Burundi	0.00	Swaziland
1.08	Italy	0.07	Niger
1.07	Switzerland	0.13	Ghana
1.07	Czech Republic	0.13	South Africa
1.00	Liechtenstein	0.21	Mongolia
1.00	Montenegro	0.25	Moldova
1.00	Armenia	0.27	Mexico
1.00	Chad	0.28	Romania
1.00	Lesotho	0.29	Kazakhstan
1.00	Bhutan	0.32	Somalia
1.00	Nepal	0.35	Mozambique
1.00	Timor Leste	0.36	Ecuador
0.99	Slovenia	0.36	Zimbabwe
0.98	Congo, DRC	0.37	Botswana

Table 5
Potential internal compared to imported runoff based on cell shares.

Ratio of internal runoff to imported runoff	Hydrologically very independent countries	Ratio of internal runoff to imported runoff	Hydrologically very dependent countries
2004.0	Timor Leste	3E–06	Egypt
58.4	Saudi Arabia	2E–05	Somalia
35.8	Malaysia	5E–05	Azerbaijan
32.5	Papua New Guinea	0.0002	Mongolia
16.8	Spain	0.0045	Bulgaria
14.2	Kyrgyzstan	0.0088	Namibia
13.9	Russia	0.0295	Israel
13.1	Montenegro	0.0366	Liechtenstein
12.2	Lesotho	0.0427	Botswana
9.8	Czech Republic	0.0617	Moldova
9.8	Guinea	0.0721	Congo Brazaville
9.7	Costa Rica	0.0743	Benin
9.3	Norway	0.0865	Romania
9.3	Equatorial Guinea	0.0989	Paraguay
9.1	Sweden	0.1052	Yugoslavia

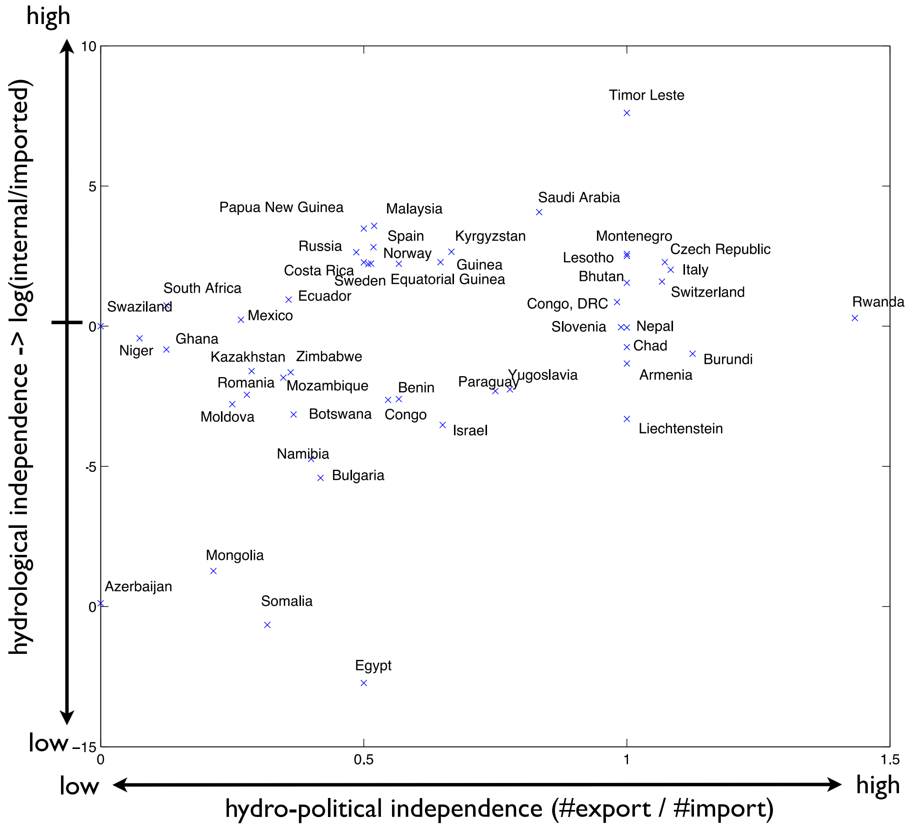

Fig. 7. Hydro-political dependency of countries, based on drainage cells and runoff. The horizontal axis captures the number of countries to which a given country exports drainage cells, divided by the number of countries from which the country imports drainage cells. The higher the value on that scale, the more independent the country is. The vertical axis indicates the ratio between internally generated runoff and vs. imported runoff.

international river treaties, cooperative and conflictive events in international water catchments (events data), respectively.

Brochmann and Gleditsch (2012) seek to explain conflict in the form of MIDs. Their data build on and also extends the TFDD data (see also Owen, Furlong, & Gleditsch, 2004). They study the effects of various factors on conflict, including upstream/downstream river geography. As stated in the codebook of Brochmann and Gleditsch (2012), "this dichotomous variable indicates whether the states in the dyad are in a pure upstream/downstream relationship. The value is 1 for dyads where there is an upstream/downstream relationship and 0 otherwise. In dyads with more than one shared basin this variable is assigned a 1 only if there is an upstream/downstream relationship in all the shared basins and all with the same country upstream." The empirical analysis shows that "basins with an upstream/downstream configuration increase the risk of conflict" (Brochmann & Gleditsch, 2012: 519).

Zawahri and McLaughlin Mitchell (2011) focus on international river basin cooperation and measure this outcome variable with water-related treaties between riparian country dyads. Their explanatory model includes various potential determinants of cooperation. Most relevant for our purposes here, Zawahri and McLaughlin Mitchell (2011: 850) argue that "power asymmetries are more likely to produce bilateral treaties" between states over water. The distribution of power is measured by upstream and downstream countries' military capabilities. The authors find that "increases in the upstream state's CINC score [for military capabilities] result in significant increases in the formation of bilateral accords" (Zawahri & McLaughlin Mitchell, 2011: 850).[6]

Brochmann (2012) also focuses on international river basin cooperation, but she uses event data from the TFDD's Basins at Risk (BAR) scale (Yoffe et al., 2003). This scale "measures the intensity of different water events occurring between riparian states." While the author focuses mainly on whether the existence of a water-related treaty facilitates cooperation between country dyads, she also considers the geographical configuration of a river. Her upstream/downstream variable "is coded 1 if the two countries in the dyad have a clear upstream–downstream relationship" (Brochmann, 2012: 153). She finds that an upstream/downstream relationship indeed facilitates water-related cooperation.

For reasons of simplicity and transparency, we replicated the three studies, then replaced their upstream–downstream variables with the four new hydro-political dependency variables from our dataset, and examined whether and how the results changed. We did not change the original estimation strategies, model specifications, or control variables. However, we are facing two important limitations. First, both Brochmann and Gleditsch (2012) and Brochmann (2012) use the country-dyad-year as the unit of analysis, whereas our data are more disaggregated, because we rely on the country-dyad-river basin-year as the unit of analysis. Zawahri and McLaughlin Mitchell (2011), in contrast, use the country-dyad-river basin-year as the unit of observation. This means that we need to aggregate the data for two of the three studies. Second, our dataset covers around 450 international river basins, whereas the three studies, because they are ultimately based on the TFDD data, rely on information on around 260 basins. For the former two studies, we can bring all new data to bear indirectly, because of the required data aggregation. For instance, if for country dyad A–B the TFDD covers two shared river basins whereas our new data covers four we simply use the data for all four basins to construct the overall river geography for the respective country dyad. Due to the

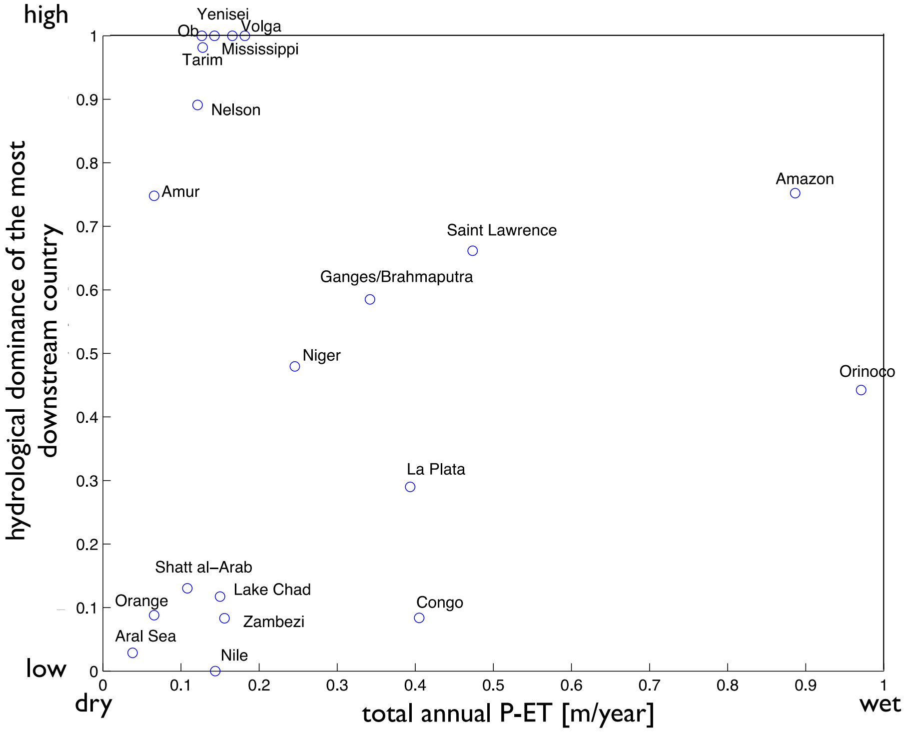

Fig. 8. Hydro-political dependency structure of international river basins.

high accuracy of our data, an upstream/downstream relationship always exists in our data. We thus focus on whether the first state in a given dyad is the upstream country or not. For re-examining the Zawahri and McLaughlin Mitchell (2011) model we are limited to the overlap between the river basins included in both the TFDD and our dataset. We calculated their power variables via multiplication of our hydro-political dependency indicators with the CINC scores.

We use two steps to evaluate how using the new data affects existing results. We first replicate the original results, calculate first difference estimates for the variable(s) of interest, and compare these with the first difference estimates for the new variables. A first difference estimate captures the change in the predicted probability (in the form of percentage points) of observing an outcome (i.e., $y = 1$) as a given explanatory variable changes values from its minimum to its maximum, all other explanatory variables held constant at their medians or means (King, Tomz, & Wittenberg, 2000).

In a second step, we compare the areas under the curve of Receiver Operator Characteristic (ROC) plots. ROC plots show the extent to which models with more predictive power generate “true positives at the expense of fewer false positives” (Ward, Greenhill, & Bakke, 2010: 366). Thus, a perfectly predictive model would correctly classify all empirically observed outcomes (i.e., $y = 1$) and never generate false positives, although our estimations predict the opposite. As noted by Gleditsch and Ward (2013: 23), any “threshold for considering an event as predicted

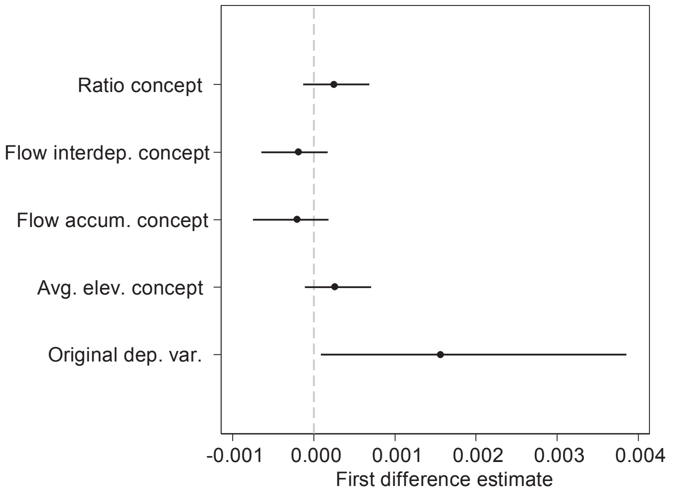

Fig. 9. First difference estimates for Brochmann and Gleditsch (2012: Model 6.4): simulated estimates are based on 1000 draws from a multivariate normal distribution. Horizontal bars pertain to 90 percent confidence intervals. First difference estimate of 0 marked with vertical gray line.

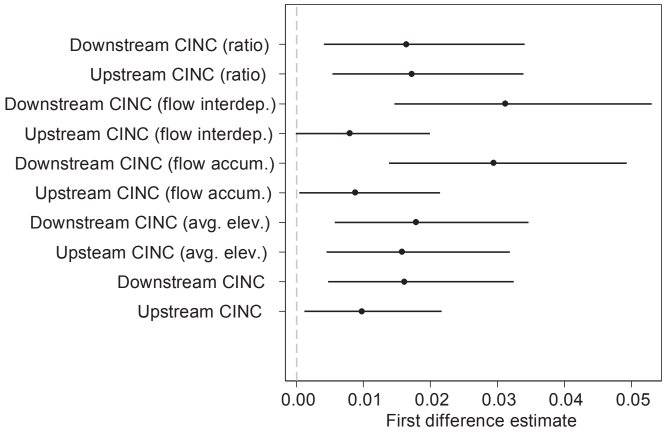

Fig. 10. First difference estimates for Zawahri and McLaughlin Mitchell (2011: Model 2.2): simulated estimates are based on 1000 draws from a multivariate normal distribution. Horizontal bars pertain to 90 percent confidence intervals. First difference estimate of 0 marked with vertical gray line.

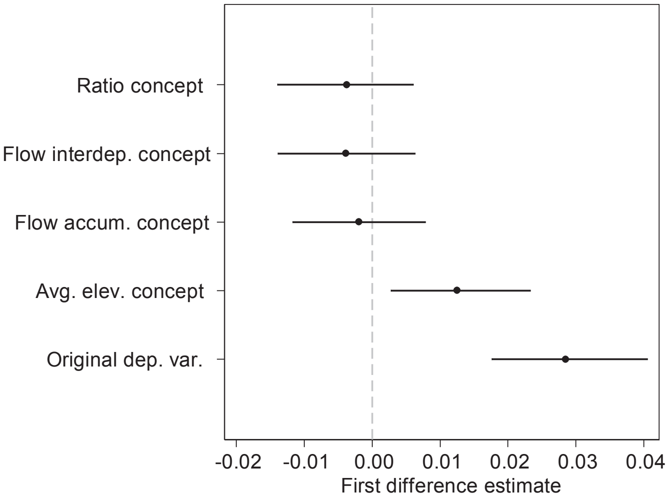

Fig. 11. First difference estimates for Brochmann (2012: Model 2.1): simulated estimates are based on 1000 draws from a multivariate normal distribution. Horizontal bars pertain to 90 percent confidence intervals. First difference estimate of 0 marked with vertical gray line.

could be seen as an arbitrary description of the continuous distribution of the probabilities." Hence, the ROC curves approach is arguably very precise in showing the predictive power of models. The ROC curve statistic, the area under the curve (AUC), theoretically varies between 0.50 (no predictive power) and 1.00 (perfect predictive power).

Specifically, we focus on what can be considered the core explanatory model in each of the three studies (Model 6.4 in Brochmann and Gleditsch (2012: 525); Model 2.2 in Zawahri and McLaughlin Mitchell (2011: 848); Model 2.1 in Brochmann (2012: 156)). Figs. 9–11 and Table 6 summarize the results.

Several key findings emerge. First, we were able to fully replicate the results reported in the three papers, as can be seen from the positive and statistically significant estimates for the "original dependency variable" in Figs. 9 and 11, as well as the positive and statistically significant estimates for "Upstream CINC" and "Downstream CINC" in Fig. 10. The interpretation of these estimates is very simple. For instance, when increasing the "original dependency variable" in Fig. 9 from its minimum (0) to its maximum (1), the probability to see the onset of a MID increases by 0.002 percentage points.

Second, while the results when using the new data are still in line with the original results of Zawahri and McLaughlin Mitchell (2011), they change with respect to Brochmann and Gleditsch (2012) and Brochmann (2012). With the exception of one of our four hydro-political dependency variables in the Brochmann (2012) model, we do not find a significant effect of the dependency variables and the point estimates are much smaller or even negative, compared to the original point estimates. The smaller confidence intervals in the Brochmann and Gleditsch (2012) model, when using the new data, also suggest that the estimates are becoming more precise.

When comparing the predictive power of the models (Table 6), we see that the new data and dependency variables result in an improvement, but this seems to depend on the outcome variable to be explained and the explanatory measure of choice. The AUC statistic for Brochmann and Gleditsch (2012) is relatively high, with a value of 0.8402. Our measures perform similarly well. Note, however, that three of them (flow accumulation concept, flow interdependence concept, and ratio concept) perform better than the original variable in predicting the onset of MIDs, while the remaining alternative item does slightly worse (average elevation concept). The AUC statistic for Zawahri and McLaughlin Mitchell (2011) is slightly below the estimate of Brochmann and Gleditsch (2012), as we obtain a value of 0.7944. The different outcome variable of these two studies is likely to be the major reason for this. Here, two of our alternative variables (average elevation concept and ratio concept) perform worse than the original item used in Zawahri and McLaughlin Mitchell (2011), while two others (flow accumulation concept and flow interdependence concept) improve the predictive power. Finally, the model in Brochmann (2012) is characterized by the lowest predictive power (0.7073) of all original studies. This might be the result of aggregation of the ordinal BAR scale to a binary variable, i.e., information is discarded and it may then be more difficult to predict outcomes accurately. This seems to affect our measures as well, though: all four alternative water dependency variables that are based on our new dataset perform worse in predicting cooperation than the original upstream/downstream variable used by Brochmann (2012). The differences are only marginal, though.

Conclusion

In this paper, we have presented a new geo-spatial dataset. In so doing we have highlighted what we regard as the most innovative facet of the new data, namely that it can generate more precise and nuanced information on hydro-political dependencies among riparian state in international river basins.

To illustrate the ways in which the new data could contribute to research on international water cooperation and conflict, we show that replacing much simpler data on river geography in three published study has significant implications for their results. The main result of this exercise is that, in contrast to a widespread presumption, upstream–downstream asymmetries appear to have a very small or no significant effect on international water cooperation and conflict.

Revisiting the three publications also makes it obvious, however, that more research is needed in this area. First, datasets need to be augmented to all international river basins covered by the new data, so that inferences can be drawn from the full population of basins. This requires a major data collection effort, particularly with respect to information on treaties and cooperative and conflictive events. Second, it will be interesting to explore whether different degrees of hydro-political dependency are likely to affect not only

Table 6
Predictive power – area under curve.

	Area under curve comparison I		Area under curve comparison II		Area under curve comparison III
Brochmann and Gleditsch (2012)	0.8402	Zawahri and McLaughlin Mitchell (2011)	0.7944	Brochmann (2012)	0.7073
Avg. elev. concept	0.8400	Avg. elev. concept	0.7938	Avg. elev. concept	0.6894
Flow accum. concept	0.8413	Flow accum. concept	0.7958	Flow accum. concept	0.6850
Flow interdep. concept	0.8410	Flow interdep. concept	0.7961	Flow interdep. concept	0.6849
Ratio concept	0.8418	Ratio concept	0.7929	Ratio concept	0.6857

cooperation or conflict per se, but how they influence the forms in which countries cooperate and design institutional arrangements for managing river basins.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.polgeo.2014.05.004.

Endnotes

[4] A MID involves threats, displays and uses of military force among states (Jones, Bremer, & Singer, 1996).

[5] Access: http://www.transboundarywaters.orst.edu and http://garnet.acns.fsu.edu/~phensel/icow.html.

[6] The CINC score, the Composite Index of National Capability (Singer, Bremer, & Stuckey, 1972), is a state capability index that comprises information on six indicators: military expenditure, military personnel, energy consumption, iron and steel production, urban population, and total population.

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